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Reducing Head Mounted Display VR Sickness Through Dynamic Field of View Constriction

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Abstract

Although virtual reality (VR) head-mounted displays (HMD) have been in use since the mid-1960s, the surge in public awareness and access to VR had spurred an increased interest in all industries to investigate the potential of VR as an interaction modality associated with high subjective presence. Many challenges need to be addressed through the disciplined application of research methods, especially combating VR sickness, if this potential is to be realised. This Engineering Doctorate thesis reports a series of investigations within the context of real-world development with a partner company (BMT Defence Service, a naval engineering consultant). The primary interest of the thesis is in the potential of VR for developing cases and uses for this technology in training. The target modality of training was a portable set-up, i.e. sitting down with a laptop, HMD and a game controller. This set up would prove beneficial for providing axillary training to personnel who are not always able to receive regular on-board training. It would also prepare people for situations which are difficult to simulate in real-world conditions. Example cases included familiarisation, line of sight tests, hazard recognition and evacuation procedures.

An initial study of VR HMD experience in training scenario highlighted VR sickness as a key limiting factor for usability thus focusing the research on identifying and reducing the factors which induce VR sickness. Prior research suggest that static field of view restrictions could help but only at the cost of loss of presence. There were no reported studies of the effects of restricting the field of view dynamically thus this thesis presents two investigations of dynamic Field of View (FOV) constriction triggered by movement in a virtual space. It was hypothesised that a reduction in FOV reduced the induction of VR sickness. The problem with doing so however was that it may negatively influence presence as the change in FOV could distract the user. This thesis reports the development of a method for adjusting FOV to reduce simulator VR without loss of presence. Two dynamic FOV constriction studies are reported. The first failed to demonstrate a clear effect but subjective user reports suggested methodological and experiential issues in its design. Meanwhile, research into a similar method was published at the 3DUI Symposium at IEEE VR 2016. Fernandes & Feiner (2016) [1], who demonstrated that dynamic FOV constriction can reduce VR sickness without compromising presence. However, their work used interaction scenarios with normal walking in an unchallenging virtual environment. Users were not subject to the types of motion which literature suggests are most likely to induce sickness.

Consequently, the second DFOV constriction study tested VR sickness reduction in

more discomforting situations via involuntary movements and animations on the virtual character and camera. Many of these animations and movements are typical in first-person applications and yet are absent from VR applications. These include for example head-bobbing, falling animations, stumbling, and forward rolls. The aim was to test whether DFOV constriction could allow VR developers to include such facets in future development. It showed that extreme movements still generate VR sickness, despite the use of DFOV constriction, but subjective reports suggest some users appear to benefit. Further research is recommended on introducing user control to the extent of DFOV manipulation. The thesis concludes with an evaluation of the state-of-the-art in DFOV constriction as a general approach to immersive VR interactions, including how the human vestibular system may limit DFOV effectiveness as a means of controlling VR sickness.

Chapter 1

Introduction

This thesis was authored by an EngD student at the University of Bath. As part of the postgraduate course, the author was partnered by a sponsor company (BMT Defence Services Ltd or BMTDS). BMTDS are primarily engineering consults and designers for naval and land vessels and vehicles. The department the author was placed in (Information Services and Assurance Support) was looking to expand its remit of using new consumer technologies to provide industry-standard technical solutions and training. This would lead to the exploration of the role of consumer virtual reality (VR)

The research presented focuses on the usability of consumer head-mounted displays. Initially, the author's aim was to evaluate and explore areas of naval training where the use of immersive HMDs would be beneficial. This research was done as a result of developing VR applications and gaining feedback and suggestions from potential end users. A study was conducted in order for the author to further develop methods of experimentation for this purpose. However, after analysis of the results, it was apparent that participants' discomfort was a major factor in the failure of the design. Further development projects which required a portable VR setup highlighted this problem.

During this 4-year research project, the successful emergence of consumer VR began with products such as the Oculus Rift (OR) [2]. The subject of this thesis is a method for mitigating VR sickness. This was in response to the need to create VR applications for portable, static setups, i.e. where the user is required to sit/stand in one place while controlling locomotion with a peripheral device. Due to the sensory mismatch between what the eyes are perceiving and the (lack of) inertial force on the body, there is a greater risk of inducing VR sickness. The developed method uses dynamic constriction of field-of-view during virtual locomotion performed using a game controller. The aim was to develop a method of mitigating VR sickness without intruding on the user's experience and immersion. A secondary aim was to allow for more erratic animations and involuntary movements in VR, i.e. camera movements not initiated by the VR user. VR development standards recommend against implementing such animations as it can be a primary factor in inducing VR sickness. However, for the sponsor's needs, it was important to have this facility.

1.1 Defining Immersive HMD

The research was conducted using the Oculus Rift prototypes. Within the context of this thesis, the term 'immersive HMD' refers to a head-mounted display with a relatively wide field of view, low-latency head-tracking, stereoscopic capabilities, and most importantly, designed to occlude all peripheral vision so that none of the real world environment can be seen.

The introduction of the Oculus Rift Development Kit 2 (DK2) helped to mitigate some of the barriers to immersion which were present with the Oculus Rift Development Kit 1 (DK1). Most notably, the screen resolution and graphical fidelity were vastly improved, with the refresh rate being increased from 60 to 75fps [3, 4]. The greatest number of reported complaints about DK1 were related to feelings of sickness [5]. The DK1 had an adequately low latency (50-60ms end-to-end latency) and fast head tracking, with a 90-degree field of view, and a full stereoscopic vision. The screen, however, though good enough to convey a sense of depth perception, was of relatively low resolution (640 x 800 per eye), and there was a smudging effect when the user moved their head [4]. Oculus implemented solutions to reduce this artificial motion blur, significantly reducing the number of reported instances of VR sickness during internal demonstrations of DK2. This OR prototype was used in all studies in this thesis.

1.2 Background on Company Work

The first months of the author's time at BMTDSL was spent on research projects with point-cloud processing and registration. It was part-way into the first year when the focus of research was changed to Virtual Reality, and the author began working with the Oculus Rift DK1. Initial projects were simple walkthroughs or static viewing experiences, where the user could wear the HMD and view or walk around a CAD model of certain vessels. These included models of existing in-service vessels as well as future concept designs. Demonstrations were then developed geared towards layout familiarisation, line-of-sight testing and training. For the remainder of the author's time at the company, the focus was on creating a VR training development platform. This drove much of the research discussed in this thesis. This was during a time where a static VR set up with traditional vection (sitting down and moving a character with a game controller) was the standard method of interaction. Some of the most frequent criticism was to do with the feeling of discomfort or disorientation. The author focussed on a number of improvements in UI design, optimisation and refined controller-based movement. However, over time it was apparent that a novel approach to combating VR sickness was needed.

1.3 Early Research

The domain of early research was exploring where and how consumer HMDs would benefit training in a naval defence and engineering setting. BMTDSL have a focus on naval platform training and ship design. The original aim of the study was to explore where and how the OR would be most effective in reducing training burden [6]. Apart from availability, benefits include portability and ease of use, providing opportunities for off-base or on-board virtual training.

During the early stages of the project, some proof-of-concept VR applications were developed. At the time, the OR was in its first round of development prototypes. Some of these demonstrations started off as simple walkthroughs, which allowed the user to move around different naval platforms and experience this kind of high-level VR for the first time. There were some early experiments done with different peripheral devices such as the Microsoft Kinect 1. However for the purpose of the tasks being developed, these devices were deemed unnecessary as they provided little value to the type of training being developed. Throughout this period, the VR applications were shown to a variety of users, which included staff members within the company and other UK defence-related organisations. The "Replenishment at Sea" application (see figure 2-1 and Section 2.4 on page 17) was the most demonstrated as it represented the company's goals and strengths. Over time the demo evolved to include a multitude of platforms and scenarios, as well as major cosmetic improvements.

This was also used as a way to engage potential users in a conversation about where they could envision this technology (the OR) being used. The main objective was to identify an area on which to focus the research. These potential areas included (Bridge) Command Training, Maintenance and Engineering, Fire and Evacuation, Replenishment at Sea and Emergency Breakaway. Whenever the demo was shown to a new user, they were asked for feedback on the demo itself, as well as whether they could see it as a valuable application of VR technology, or whether there were alternative disciplines which would benefit more.

This exercise was mostly useful for evaluating how user-friendly the interaction was, particularly for users not familiar with gaming technology. There were however, a great number of influential factors which would subtract credibility from some of the feedback. Many users were seeing this kind of HMD technology for the first time. This influenced their response due to the novelty factor. It was unclear whether they would give the same feedback after multiple uses.

The first study looked at HMDs like the Oculus Rift as a preferable interactive modality, compared to more traditional methods of training such as textbooks/manuals and video. While adding more game play elements could be seen as more involving, it could become a distraction and influence the results, e.g. lower performance could be the result of difficulty with learning the game play, as opposed to it being the result of how the information is presented. A decision based task would allow for distinctions in performance, while simplifying the game play element, leaving the user to focus more on knowledge acquisition.

1.4 VR Sickness Research

VR sickness refers to the adverse physiological reaction experienced by the user as a result of using a head-mounted display or other immersive VR hardware. Many tangible causes of VR sickness come from problems such as vergence and eye distance in stereoscopic viewing modes [7, 8], latency and image quality. Many of the other influential factors are explained in detail by research into the vestibular system, and cue-conflict theory which occurs when the perceived movement is different from the exerted force on the rest of the body [9, 10, 11]. Symptoms of VR sickness include headaches, stomach awareness, nausea, vomitting, pallor, seating, fatigue, drowsiness and disorientation [12].

As many of the applications developed by the author required movement within the virtual world by simulating walking, a method for mitigating VR sickness was required. At the time of writing, there are consumer HMDs which allow users to physically move within a limited area. While this greatly reduces the induction of sickness, the requirement of the author was that a method for more static VR setup needed to be developed for portability. The most prominent example of this is being sat in front of a machine with a controller in hand, which is used to move a first-person avatar in the virtual environment.

A method using dynamic field-of-view (DFOV) constriction was developed by the author. Artificial FOV reduction [13] was used in response to the participant's translational movements, i.e. when the character moved around the environment. The final version of this method took both movement and rotation into consideration, where the FOV constricts over time. The rate of constriction was dependant on the speed of movements and rotation. This method at the time had not been attempted. It was hypothesised that using DFOV constriction would not only mitigate VR sickness, but it would do so while allowing the participant to maintain a sense of presence.

1.5 Thesis Overview

This thesis reports the research in two main phases. The first phase is related to research in the application of the consumer HMDs, where a pilot study was undertaken. The second phase is related specifically to VR sickness. A pilot study is outlined in this phase followed by the main study which tested the author's implementation of Dynamic Field of View Constriction. The results of these studies are reported, followed by a conclusion and reflections on future direction of this research, along with an explanation of the significance of this research.

Chapter 2

Study Design for Determining Effectiveness of Immersive HMD

This chapter outlines a preliminary study exploring the effectiveness of immersive HMDs in training applications. The focus on improving the usability of HMDs in solo preparatory training did not emerge as a result of this proposal. At the time, the wider application of consumer VR was being explored. A pilot study was carried out yielding results which caused the author to reconsider the approach to VR research. This included the role of VR sickness in the user's experience, which had not been factored in at the time, despite the fact that the author fully optimised the application in order to maintain a solid framerate required for VR applications. The study outlined in this chapter took an open feedback approach to understanding some of the issues in using VR for on-board ship training. The components in the study included moving a first-person character in VR using a peripheral game controller, situational and hazard awareness, and multiple choice questions.

2.1 Introduction

The aim of this study was to test how effective immersive HMDs would be to deliver the training provided by the sponsoring company. The test scenario was based on a new standard naval procedure for vessels which at the time were in design or construction. The measures included participant performance scores on a task, as well as data collected from questionnaires. These questionnaires were designed to gauge the participant's level of engagement with the VR application by measuring their sense of presence and immersion, and to see whether they had a positive effect on performance.

2.2 Literature Review

In this study, the term *human factors* refers to ergonomic considerations taken when designing virtual training. Stone (2008 and 2012)[14, 15] gives an overview of human-factors related issues which in this context refers to the physical and psychological ergonomics of a simulation system. The core idea is that the training implementation should always aim to reduce as many distractions (from the task) as possible while providing a rich environment that would reinforce the intended training and knowledge retention [16]. Task fidelity refers to the design features which make use of different modalities and interactions. Task fidelity is split into two major approaches. Firstly, physical fidelity, which focuses on recreating environments and appearances of important objects in a familiar and/or photorealistic way. Secondly, psychological fidelity, which focusses on reproducing real-world behaviours (e.g. realistic physics). Task fidelity encompasses the ability to find a balance between the two approaches, depending on what the task requires. More complex applications could contain a high level of both, though this would either require a relatively large amount of computing power or be set in a very limited virtual environment such as a virtual home tour. If the task is based on perceptual motor skills, then arguably there would be less emphasis on the realistic look of the simulation, and more emphasis on the interaction and behaviour of objects, even if they were simplistic abstractions, i.e. psychological fidelity. An example of this would be shooting at moving targets represented by circles; a task designed to test reaction and accuracy. If the task was cognitive-based, e.g. navigation or decision-based activities, then having higher physical fidelity would be important. Clutter, cognitive overload and cognitive tunnelling, i.e. not overwhelming the user with too much stimuli [17], are big issues to take into consideration with fidelity. It is also possible to have a hypo-fidelity condition, where the environment is not stimulating enough. Context fidelity refers to the use of background details in a virtual environment. These include sounds, ambient visual content, features within the navigation space, environmental clutter and interactions with other actors. Hyper-fidelity, (i.e. more focus on representing realism visually) results in loss of focus from the task, and it can also contribute towards breaking the illusion of the virtual world. HMDs such as the OR allow the user to view the virtual world with near full-depth perception. An advantage of this is a sufficient (abstract) representation of the target environment [14] [15], coupled with accurate depth/spatial information good enough for decision-based or familiarisation scenarios. For example, if the user was asked to familiarise themselves with the layout of the engineering deck of a ship, they may not need the precise detail of engine components and other complex machinery spaces, as long as there was a defining abstract representation of each of the rooms which could be transferred to the real environment. It has been shown that the use of spatial information can reinforce cognitive processing in learning tasks [18]. 3D perceptual displays were compared with typical monitor displays [18] and found that using the extra depth cues and making more visual information available to the participant enabled them to employ more strategies for learning and improve task performance. Intrinsic learning can be facilitated and assessed within virtual environments [19]. Within the task designed in [19], participants were asked to recall a series of letters or a series of objects. These sequences were presented in two ways; on a flat screen as a simple series of objects, and in a virtual 'natural' environment. Locomotion in the VE was achieved by giving the sense that the participant was flying over a landscape environment at a low altitude. While they were 'flying', a series of letters or objects would appear on the ground in sequence. Learning was tested by either guiding the participant through the task (and making them aware they were to be tested), or they were asked to simply observe the virtual scene without any indication of the task. It was found that sequential recall was improved with the more engaging VE conditions, regardless of whether or not they were guided. Presence is a concept which is typically used to describe perceived involvement in the virtual world [20, 21, 22]. These include the user's level of involvement in the task and the believability of the virtual world. A review was conducted on the role of presence in validating the efficacy of cybertherapy [23]. Overall, in studies where HMD conditions were compared with other VR modalities such as CAVE and monitor screens, participants reported higher levels of presence when using HMDs. It was found that the measure of presence and its correlation to task outcome was varied as presence was universally measured using generic VR methods. Although there are some competing theories on what defines presence and level of immersion [20], [21], [22], there are some common features. These include the user's level of involvement in the task and the believability of the virtual world (physically and psychologically). There are competing conclusions on whether the user having a greater perceived sense of presence influences (increases) their performance of their tasks. A review was conducted on the role of presence in validating the efficacy of cybertherapy [23] (therapy given through digital medium such as web and VR). It was found that the correlation between presence and task outcome was varied as presence was universally measured using different questionnaires. They did, however, find that the most common questionnaires used were the Witmer & Singer version [20] (17 out of 50) and the Slater version [21] (11 out of 50). They conclude that "in cybertherapy, the mediated environment with its hardware and software is an integral part of the treatment and coincides with the intended outcome. Therefore, the concept of presence, defined as the sense of being in the mediated environment, is especially relevant in cybertherapy, in both immersive and non-immersive environments". Evaluating presence is treated as a goal of creating effective virtual applications according to their cross-study, thus validating the value of using such a measure as part of evaluating the effectiveness of VR applications. In identifying which tasks to apply for this research it is as important to determine what levels of affordance can be catered for using immersive HMDs. Affordance in the virtual world refers to the perception of an action, where a virtual object's behaviour is similar to what the observer expects [24]. For example, if a knob on a door is afforded a twisting action, it is expected to react in a certain way. The level of affordance fidelity is dependent on how much the task requires, and whether it contributes towards the immersive experience. For example, being able to break an object by shooting it, although not pertinent to the task, may still enhance the experience. Regia-Corte, Marchal, Cirio and Lcuyer (2013)[25] explored the use of VR and HMDs to test how much affordance of an object can be replicated in the virtual world. The participants in their study were presented with a plank, at varying gradients. They were 'stood' at different positions on the plank, and the plank itself was made from various materials. The participants were asked whether, in their current situation, the plank could support a human standing in an upright position. The results showed that the participants were able to make accurate judgements, such as how much friction the surface had, their position on the board, and whether it was too steep to stand on. The literature in this section outlines considerations for designing VR HMD training solutions. The OR and other such immersive HMDs bring new possibilities for portable and cost-effective training. They must, therefore, be evaluated for their potential for reducing training burden. The measure of presence and immersion is of value to this research as it serves to give an indication as to whether the increase in immersion is significantly beneficial for virtual training outcome.

2.3 Hypothesis

It was hypothesised that the training application developed by the author using the immersive VR condition would increase the user's reported sense of presence compared to with non-VR conditions. Users in this condition were also expected to achieve the highest performance scores. Therefore an increase in score was expected to correlate with a higher reported sense of presence.

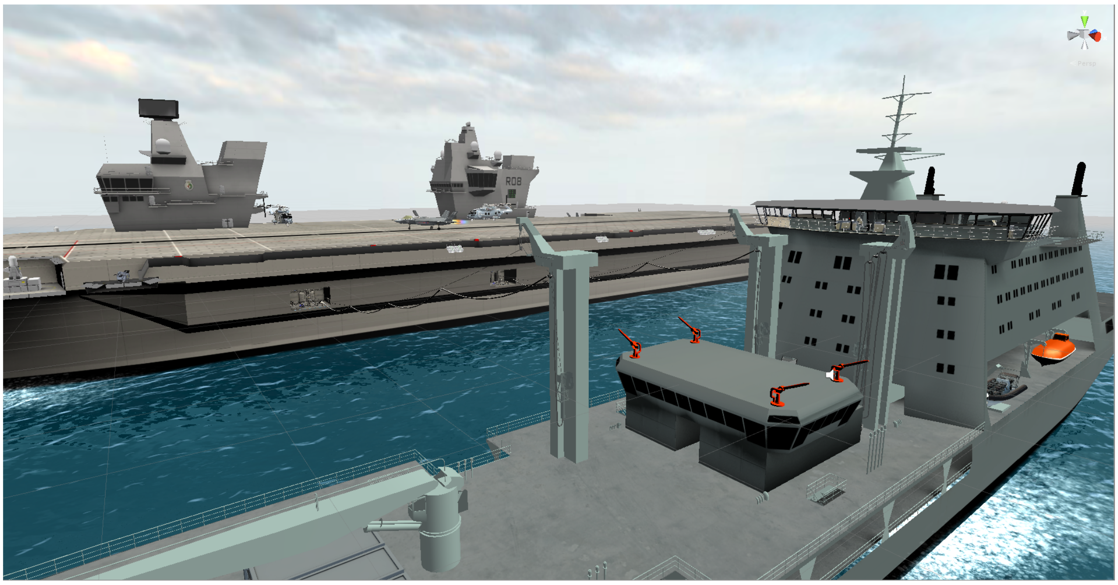


Figure 2-1: External view of the Mars tanker replenishing the QEC aircraft carrier

2.4 Scenario: Replenishment at Sea (RAS)

2.4.1 Motivation

The purpose of this study was to test the suitability of the VR application as a valid training tool. The procedure of Replenishment at Sea (RAS) has been practised for a considerable time. This version of RAS is different as the Mars tanker (in production) was designed to refuel the QEC aircraft carrier. Due to the size of the aircraft carrier, there are new line-of-sight challenges with the QEC (see figure 2-1). For example, it is difficult to judge the firing range of the harpoon used to shoot the fuel guiding ropes over QEC as the deck of the fuelling vessel is significantly lower than the QEC's. As standard training for this was still in development, training facilitators were open to using new technologies. This section outlines the RAS scenario, which contains procedures for the Mars tanker safely replenishing the QEC aircraft carrier on the sea. Using a small number of participants with specific backgrounds, their feedback and suggestions were recorded and categorised using Thematic Analysis [26, 27]. The author was the supervisor for all trials.

2.4.2 Requirements for Participant

The procedures simulated in this scenario encompass different stages of RAS at an overview level. The current implementation is designed to give an overview of the im-

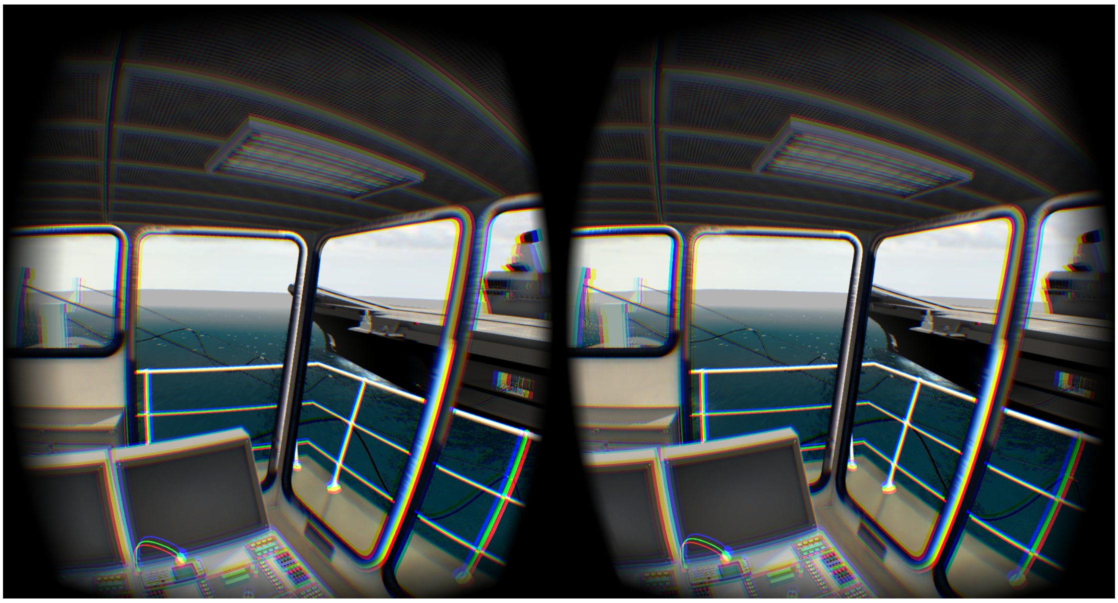


Figure 2-2: Screenshot of OR view from first-person character on the bridge of the Mars tanker during a RAS operation

portant stages, decisions and problems involved. The user (in the interactive conditions) has the ability to walk around the bridge of the Mars tanker (see figure 2-2).

2.4.3 Equipment and Implementation

The Oculus Rift Development Kit 1 specifications [4] (5.7” 640x800px per eye, 60 Hz OLED Display, horizontal FOV 110 degrees) was used, using a beta version of Oculus SDK and runtime environment. The laptop used with GTX 675M Graphics, 16Gb DDR3 RAM, Intel Core i7-3510QM CPU @ 2.30GHz. Test VR application was built with Unity 4. A standard wired Xbox 360 Controller for user input was used. Audio was not implemented in the application.

2.4.4 Control and Input

Each user was given a standard PC game controller. Participants controlled a first-person avatar using the left analogue stick for movement and the right analogue stick for rotating the character. The UI interface for the questions, answers and hints (see figure 2-5) was controlled by the supervisor, who also triggered events such as the Mars tanker approaching the carrier.

Figure 2-3: Screen shot from a video recording of a trial. The camera was angled to capture the participant as well as the screen showing what he/she was viewing in the HMD

Approach

The simulation began with the Mars tanker being placed at a distance behind the QEC. The speed of both ships was matched at this point. Throughout the trials, the participants were asked questions depending on which stage they were at. The questions at this stage were about checking the approach vector, sea conditions and whether all aircraft were grounded. The questions pertained to whether it was safe to approach the QEC, and how the participant should do so (see figure 2-6). When the Mars approached the QEC, a safe distance needed to be maintained between the two vessels to avoid collision. Approaching too close would have increased the chance of collision due to the hydrodynamics of the wake/vortex created by the QEC. Although the participant would receive reduced scores for a decision to move too close, they were also tested on how they corrected for the mistake. This stage ended successfully when the two ships aligned properly and were matching course and speed.

Initiating Replenishment

Due to the complexity of RAS, the full procedure was not simulated. Instead, the participants were tested on the general steps taken to ensure the safe transference of fuel and phone lines prior to the actual refuelling. Crew members on the Mars use a mounted gun to shoot the lines across (telephone lines, measurement distance line, fuel hose support lines). This involved shooting projectiles with lines attached across the bow of the QEC. Prior to this, the participant needed to recognise that orders need to be given to ensure the safety of the crew on both ships, such as giving the order to brace, and identifying when it was safe to fire. The task is further outlined in Section 2.6.

Hazard Recognition

During the course of the task, there were a couple of hazards which the participant needed to look out for. At the beginning of the trial, they were informed that all aircraft should be grounded before replenishment can be initialised. Throughout the trial, there is a jet plane constantly circling the area. Without being prompted, they needed to inform the supervisor, or at least comment that the plane is flying around when it should have been grounded.

Another requirement was that the path of the ships needed to be clear before they could initiate replenishment. During the stage where the Mars is aligning with the QEC, another ship can be seen in the distance in the path of the vessels. Again, it was up to the participant to point this out to the experimenter. At the end of the trial, these hazards were pointed out to the participant if they failed to spot them themselves.

2.4.5 Learning and Training

At the time of this study, training material for the new RAS procedures was being written by subject-matter experts within the sponsor company. They provided the reference material for this exercise. This pilot scenario was being designed with feedback from them, and others who were familiar with the training. This ensured the material and format were close to the style the participants are used to.

2.5 Study Design

2.5.1 Training Structure

The participants were presented with a series of questions and the training phase was allocated 3 minutes. The supervisor was present throughout in order to answer any queries and to input the participant's responses into the application, where it was recorded. The task was decision-based, where the user had to make choices at key moments in the scenario. These were presented as an in-game list of options. All their answers and other feedback was given verbally by the participant, where they gave their answers in the form of "A", "B" or "C", or "Yes" or "No". The supervisor input the participant's answer immediately via button press. This allowed the participant to focus their attention on the task and not have to apply cognitive resource to inputting their feedback. In particular, some users may have found it difficult to press the correct button on the game controller while their vision was completely occluded by the HMD. Verbal communication was a more naturalistic way to give responses.

If a response was incorrect, participants were given immediate feedback both via UI and verbally by the experimenter. While communications by the experimenter may reduce the participant's sense of presence (without using microphone to make the voice heard in-application), the feedback was brief and corresponded directly with in-application prompts. The scenario continued based on the decisions made by the participant. Some incorrect responses resulted in automatic failure (where trial is terminated), whereas others resulted in further choices, i.e. showing that they could correct for the mistake if possible.

2.5.2 Participant Selection

For this study, participants were specifically chosen on the basis of how valuable their feedback would be and their familiarity with the project. Half of the participants had a high level of naval knowledge and experience, chosen from the naval engineering and architecture department of the company. The other participants were from the software solutions department (in which this project was developed), and they had computing and software development experience. The difference in conditions was that the Mars would either be too far or too close to the QEC aircraft carrier after they completed the approach. Altogether 8 male participants (ages 20 - 60) were used.

2.5.3 Measures

Questionnaires

In order to measure a user's level of interaction, the presence questionnaire (Witmer & Singer, 1998)[20] was used. These tested and approved questionnaires attempt to gauge a user's experience based on categories such as visual realism or physical realism. The majority of questions are measured on a Likert-type scale [27]. The Presence Questionnaire (PQ) measures how involved the user felt they were during the duration of the HMD experience. The Immersive Tendencies Questionnaire (ITQ) measures how likely a person is to become immersed. Both questionnaires were developed by Witmer & Singer (1998)[20] who defined presence as "a subjective experience of being in one place or the environment, even if one is physically situated in another". Immersion is described as a psychological state which is invoked by an enveloping constant stream of stimuli. The ITQ is used to evaluate how susceptible to being immersed in a virtual environment an individual is. Unaltered versions of the Immersive-Tendancy Questionnaire (ITQ) and Presence Questionnaire (PQ) [20] were used. In order to categorise the participants, an 'experience' questionnaire was also developed by the author asking questions related to gaming, VR and naval experience.

Qualitative feedback

The data collected from participants consisted of transcripts of their comments and responses to questions during the trial. Throughout the trial, the supervisor made a note of what was said. Prompts for feedback were embedded in the session design and each session was recorded on video. This allowed for transcription, as well as providing a context for certain conversational points, as the the camera also captured what the user was seeing in the virtual environment (see figure 2-3). Thematic Analysis [26, 27] was used to categorise their feedback. While largely exploratory, examples of expected feedback included comments on the game design, character movement, realism of the animations and suggestions for future experiments. During the analysis, this was paired with the quantitative analysis of the questionnaires in order to identify any trends.

2.6 Task Design

Each experimental session lasted approximately 30 minutes and was composed of 4 stages. Prior to beginning the session, each participant was informed that they would be using the Oculus Rift, and that if at any point they felt uncomfortable or wanted to

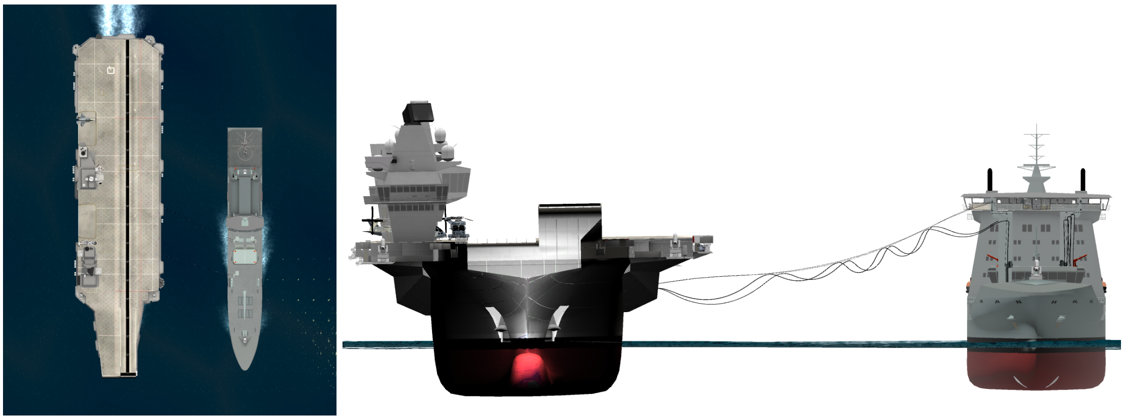


Figure 2-4: Left image shows an orthographic top down view of the vessels at the correct positions. Right image shows the same but from the front angle. These were references the participant could use for judging distance and position between the two ships

stop the experiment, they could stop at any time. Participants were then informed that they were to be recorded on video while participating in the experiment. They were told that any data collected from questionnaires and video would remain anonymous and that they could withdraw themselves and their data at any time. If the participant agreed to continue, the session began.

Preparation Stage: They were then asked to complete the Experience and ITQ questionnaires on paper. The participant was then given a quick verbal brief on the RAS process. The overview included considerations to be taken into account when approaching the QEC aircraft carrier and ensuring that it was safe to transfer the refuelling hoses. They were informed that the demo takes place from the point of view of the bridge of the Mars. Two diagrams were presented to them; each showing the separation distance between the two ships (see figure 2-4). One of these was an orthographic view from the front, while the other was birds eye view. During this stage they were informed that they must always check for obstacles in the water, and make sure that there is no activity on the deck of the QEC (see figure 2-6).

Familiarisation Stage: They were then asked to wear the OR, and allowed a short period of time to become familiar with the controls and with the Oculus Rift, and walk around freely on the bridge. During this period, the user was asked to give feedback on anything they noticed, or what they were thinking at the time. As stated in the previous section, all spoken feedback was recorded and categorised. Below is an extract from one of the transcripts:

Examiner: “So just have a walk around before we get started. Just let me know if you have any thoughts at the moment on how you are feeling or on the simulation or anything in general?"

Participant: "I feel [that I am] quite tall within the bridge at the moment. It's funny, when I stop...if I strafe to the left and I stop, my body wants to continue going a little bit. You know that sort of [motion] like if you did it in real life. So if I strafe to the left and stop, normally if you're doing that motion physically your body would react to it. It feels a little bit funny on the brain when I do that."

It should be noted that at the time strafing was implemented without knowledge of its negative effects on VR sickness. In future studies, this dimension of movement is removed from character controls.

There were three other points in the trial where the user was always prompted for feedback on what they were thinking at the time. These points were just before the approach, during the ship approach and just before the trial ended.

Initial Check Stage: Once they were ready to continue, the participants were presented with the first multiple choice question which asked which procedure they would perform first. The choices consisted of 'Prepare Rig', 'Inform QEC of Approach', 'Begin Approach' or 'None of the Above'. Another question asked whether they thought their current position was a good approach vector (see figure 2-5). Before the approach stage began, the participant was again prompted for an opinion of the situation, and whether they thought it was safe to begin the approach or not. There are implicit factors which should cause the participant to question the safety of the situation; a ship in the distance, and a jet plane taking off and landing from the QEC. This relates to the instructions given near the beginning of the session (see figure 2-5).

Approach Stage: The approach animation began, and the ship ended at a different position depending on which condition the user was placed in. They were asked to make any observations while the ship was moving (see figure 2-6). For example:

Examiner: "So any thoughts at the moment while it's approaching?"

Participant: "So [*the tanker is*] approaching [*at*] quite a quick speed, at the moment you're [*the tanker is*] going to go straight past the vessel. You want to back off."

Once this was completed, the user was asked about the separation width in another multiple choice question (Too far? Too close? Correct Distance?). During this stage, the participant could refer to the diagrams (see figure 2-4) via a head-up display. The tanker

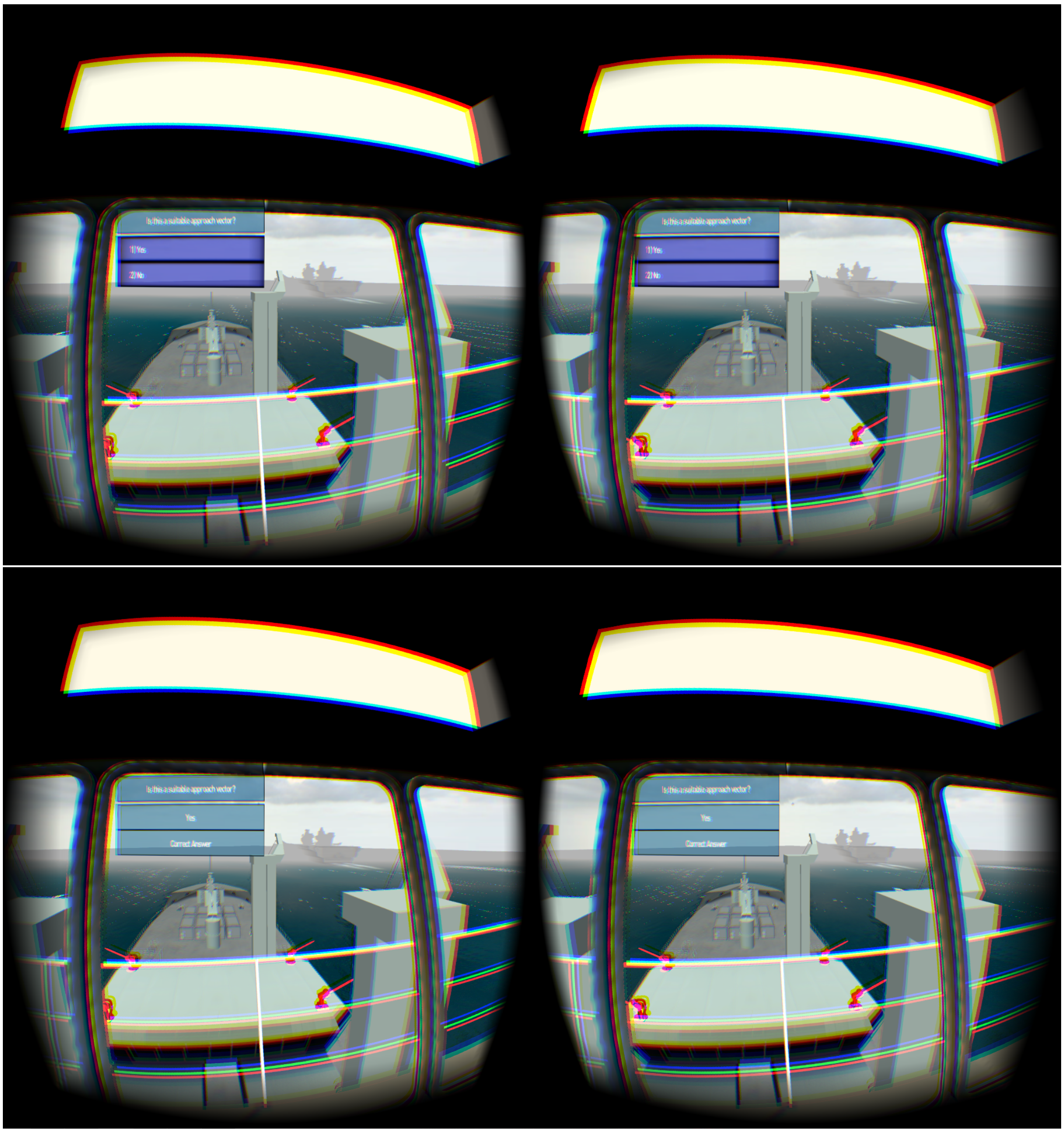


Figure 2-5: Screen-shot from trial during one of the 'Initial Check' questions. The above image is the OR view of the question being presented. The image below is the OR view of the feedback

corrected itself to the right position regardless of the answer given. The participant was then presented with a final multiple choice question relating to the alignment of the two ships. The diagram showed that the front of both ships were almost aligned with each other. They were asked to judge from the point of view of the bridge whether they were aligned. In all conditions, the Mars was positioned too far back, and needed to move forward in order to be at the correct position. For the final stage, the participant was prompted for any further comments. When the trial was completed, they were asked to complete the Presence Questionnaire.

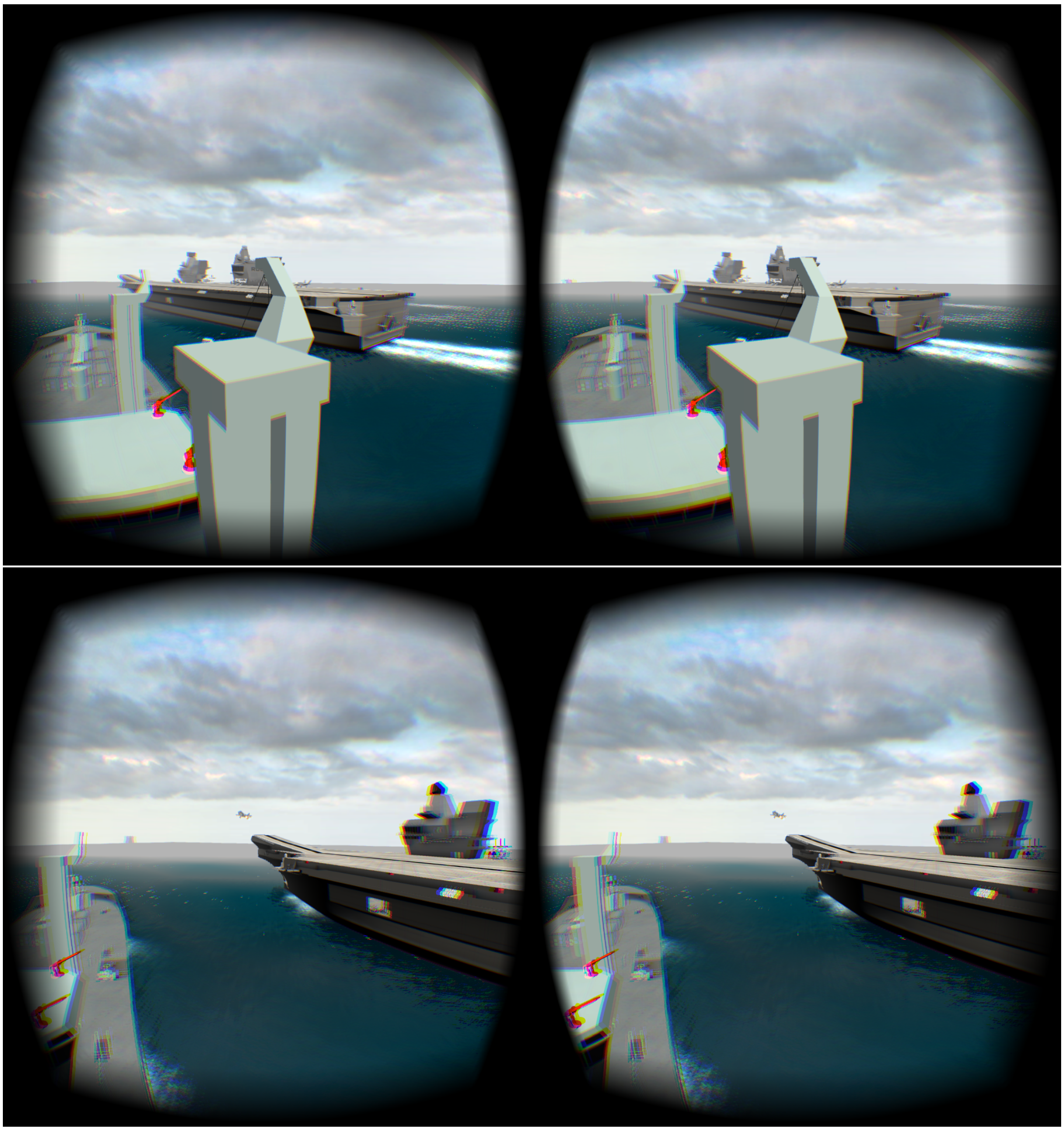


Figure 2-6: Screenshot from trial during one of the 'Approach Stage' questions. The above image is an OR view as the Mars tanker approaches the QEC aircraft carrier from the side. The image below is an OR view showing two hazards (the jet plane and the ship in the distance) which the participant should detect

2.7 Results

Exploratory factor analysis [28] was performed on each of the questionnaire datasets in order to discern any major defining trends. Typically this method is used to reduce datasets into clusters. Once the correlation matrices are generated, noteworthy results are reported. The first questionnaire to be analysed was the Experience Questionnaire in order to discern any group divisions. It should be noted that it will be difficult to infer meaning from covariate results given a small sample size of 8 participants.

2.7.1 Experience Questionnaire Results

By extracting the R-Matrix output from the factor analysis, clusters appeared which indicated that there was a division in participants. The output shown in figure 2-7. There were no correlations with reports of general motion sickness between any of the other results. There was clustering and a strong correlation between questions relating to gaming, where it can be shown that those who play games more often (**Q1**) also report a higher experience in the use of a game controller (**Q2**) and have a greater experience in First-Person games (**Q3**), and vice versa. It was also clear that there was a strong correlation in results for each of the questions related to naval experience. It could be inferred that those who reported a higher level of maritime experience (**Q9**) would also report a greater number of years in naval experience (**Q10**) and more familiarity with the RAS process (**Q11**). Most importantly it was found in general, any scores relating to gaming (**Q1,2 and 3**) negatively correlated with results from questions relating to naval experience (**Q9,10 and 11**). This shows that there is a clear distinction between those who are experienced gamers, and those who have naval experience (see clustering of results at **Q1, Q2 and Q3** and **Q9, Q10 and Q11** in figure 2-7. As a result of this analysis, it is clear that the two groups; navy and non-navy/gaming, can be differentiated by the results of **Q1**. This measure is used to see if there are any trends which occur differently in the ITQ and Presence Questionnaire depending on group categories.

Those with more HMD experience (**Q5**) mostly reported using Oculus Rift prototypes (**Q6**). Interestingly there was a strong negative correlation between naval experience and motion sickness induced as the result of using HMDs (**Q8**). However, there was also a negative correlation between the naval experience and HMD experience in general (**Q5 and Q6**). Those who had used HMDs (**Q5 and Q6**) mostly reported motion sickness as a result of using them (**Q8**). It was shown that those in the navy cluster (**Q9, 10 and 11**) had taken part in more virtual training exercises (**Q4**). Although the study suffers from an underpowered sample size, it is interesting to note that those with naval experience, regardless of HMD experience, did not suffer as much adversity. This may suggest a tolerance to simulator sickness as a result of their experiences in their line fo work.

		Q1: Do you play games often?	Q2: If you play/ have played video games, do you have experience with console game controllers	Q3: If you play/ have played video games, do you play First-Person-Perspective games?	Q4: Have you used or have experience in virtual training?	Q5: Do you/have you used head-mounted displays (HMDs)?	Q6: Do you use/have you used the Oculus Rift (Development Kit 1 or 2)?	Q7: Do you experience motion sickness?	Q8: Have you ever experienced discomfort or motion sickness as a result of using HMDs?	Q9: Do you have any maritime experience (Naval or otherwise)?	Q10: How many years of naval experience do you have?	Q11: Are you familiar with the procedures of Replenishment at Sea/ Underway Replenishment?
Correlation	Q1: Do you play games often?	1.000	.771	.714	-.878	.319	.478	-.218	.490	-.752	-.734	-.657
	Q2: If you play/ have played video games, do you have experience with console game controllers	.771	1.000	.829	-.683	.575	.717	-.393	.660	-.752	-.734	-.657
	Q3: If you play/ have played video games, do you play First-Person-Perspective games?	.714	.829	1.000	-.781	.575	.598	-.480	.405	-.934	-.876	-.764
	Q4: Have you used or have experience in virtual training?	-.878	-.683	-.781	1.000	-.218	-.204	.447	-.145	.778	.647	.733
	Q5: Do you/have you used head-mounted displays (HMDs)?	.319	.575	.575	-.218	1.000	.802	-.488	.714	-.663	-.688	-.390
	Q6: Do you use/have you used the Oculus Rift (Development Kit 1 or 2)?	.478	.717	.598	-.204	.802	1.000	-.183	.891	-.572	-.693	-.224
	Q7: Do you experience motion sickness?	-.218	-.393	-.480	.447	-.488	-.183	1.000	.098	.383	.181	.471
	Q8: Have you ever experienced discomfort or motion sickness as a result of using HMDs?	.490	.660	.405	-.145	.714	.891	.098	1.000	-.493	-.653	-.170
	Q9: Do you have any maritime experience (Naval or otherwise)?	-.752	-.752	-.934	.778	-.663	-.572	.383	-.493	1.000	.963	.802
	Q10: How many years of naval experience do you have?	-.734	-.734	-.876	.647	-.688	-.693	.181	-.653	.963	1.000	.700
	Q11: Are you familiar with the procedures of Replenishment at Sea/ Underway Replenishment?	-.657	-.657	-.764	.733	-.390	-.224	.471	-.170	.802	.700	1.000

Figure 2-7: Correlation (R-)Matrix from Factor Analysis of Experience Questionnaire. Matrix shows major cluster at bottom left (Q1, Q2, Q3 and Q9, 10, 11) where there is a division between gaming experience and naval experience

2.7.2 Presence Questionnaire Results

After identifying the clusters in the previous subsection, **Q1** from the Experience Questionnaire (figure 2-7) was used to split the participants into two groups where participants with a naval background turned out to have very low scores, while all others had higher scores. This is based on answers relating to naval experience. Factor analysis [28] was used to assess any correlations or clustering between the type of user (navy or non-navy) and the results of the presence questionnaires. Figure 2-9 shows a simplified breakdown of the R-matrix. There were only a couple of notable correlations, where sense of objects moving through space (**Q10**) was lower as the level of gaming experience went up. It was also shown that there was a report of greater (relative) proficiency with interacting and moving in the virtual world by the end of the experience (**Q27**) in the non-navy group. From the results in figure 2-8 it is evident that while most of the correlations were positive, there were some results which were lower than expected (less than middle level). There was a low score for participants feeling they were able to control events (**Q11**). There was a very mid-level response to how consistent the virtual world was with their real-life experience (**Q12**). The R-Matrix (figure 2-9) reports no strong correlation either, suggesting that all participants gave a mid-range response to this question. It was expected that at the very least, those in the navy group would give answers toward the higher or lower end of the scale. This may have been due to the novelty of using the Oculus Rift DK1 which may have exposed the participants to a higher quality of virtual reality they had not previously experienced. Other results which scored low, such as the question of how well the participant could identify sounds (**Q15**) were expected, as these factors were not present. All other scores were as expected in the simulation

2.7.3 ITQ Results

As for the PQ, the ITQ were clustered using factor analysis (see section 2.7.1), **Q1** from the Experience Questionnaire (see figure 2-7) was used a group identifier (lower score = navy). Factor analysis [28] was used to assess any correlations or clustering between the type of user (navy or non-navy) and the results of the immersive tendency questionnaires. See figure 2-11 for a simplified breakdown of the R-matrix. There were strong positive correlations in questions relating to video game habits and immersive tendencies (**Q10 and Q21**) and levels of gaming experience, as expected. There was a negative correlation between gaming experience, and how well the user reported they could concentrate on disagreeable tasks (**Q22**) (suggesting greater reported levels in users with navy background).

Presence Questionnaire	Mean	Std.		Mean	Std.
1 How much were you able to control events	3.88	1.727	17 How well could you actively survey or search the virtual environment using touch?	1.88	1.246
2 How responsive was the environment to actions that you initiated (or performed)?	4.50	1.690	18 How compelling was your sense of moving around inside the virtual environment?	5.50	.535
3 How natural did your interactions with the environment seem?	4.38	1.685	19 How closely were you able to examine objects?	4.75	1.035
4 How completely were all of your senses engaged?	4.75	1.035	20 How well could you examine objects from multiple viewpoints?	5.13	1.246
5 How much did the visual aspects of the environment involve you?	5.63	1.061	21 How well could you move or manipulate objects in the virtual environment?	2.00	1.069
6 How much did the auditory aspects of the environment involve you?	4.25	.707	22 To what degree did you feel confused or disoriented at the beginning of breaks or at the end of the experimental session?	1.75	1.035
7 How natural was the mechanism which controlled movement through the environment?	4.75	1.282	23 How involved were you in the virtual environment experience?	4.75	.707
8 How aware were you of events occurring in the real world around you?	4.63	.916	24 How distracting was the control mechanism?	2.50	1.069
9 How aware were you of your display and control devices?	4.00	1.069	25 How much delay did you experience between your actions and expected outcomes?	2.00	.926
10 How compelling was your sense of objects moving through space?	5.25	.707	26 How quickly did you adjust to the virtual environment experience?	5.88	.354
11 How inconsistent or disconnected was the information coming from your various senses?	5.25	.463	27 How proficient in moving and interacting with the virtual environment did you feel at the end of the experience?	6.00	.535
12 How much did your experiences in the virtual environment seem consistent with your real-world experiences?	4.75	.886	28 How much did the visual display quality interfere or distract you from performing assigned tasks or required activities?	2.50	.535
13 Were you able to anticipate what would happen next in response to the actions that you performed	5.00	1.414	29 How much did the control devices interfere with the performance of assigned tasks or with other activities?	2.63	1.188
14 How completely were you able to actively survey or search the environment using vision?	6.38	.518	30 How well could you concentrate on the assigned tasks or required activities rather than on the mechanisms used to perform those tasks or activities?	4.75	1.282
15 How well could you identify sounds?	4.50	1.195	31 Did you learn new techniques that enabled you to improve your performance?	4.13	2.031
16 How well could you localize sounds?	3.00	1.414	32 Were you involved in the experimental task to the extent that you lost track of time?	4.13	1.885

Figure 2-8: Means and standard deviations for results from Presence Questionnaire

	Q1: Do you play games often?		Q1: Do you play games often?
1)How much were you able to control events	.144	17)How well could you actively survey or search the virtual environment using touch?	.127
2)How responsive was the environment to actions that you initiated (or performed)?	-.267	18)How compelling was your sense of moving around inside the virtual environment?	0.000
3)How natural did your interactions with the environment seem?	.094	19)How closely were you able to examine objects?	.044
4)How completely were all of your senses engaged?	.306	20)How well could you examine objects from multiple viewpoints?	-.272
5)How much did the visual aspects of the environment involve you?	.106	21)How well could you move or manipulate objects in the virtual environment?	.423
6)How much did the auditory aspects of the environment involve you?	-.064	22)To what degree did you feel confused or disoriented at the beginning of breaks or at the end of the experimental session?	.480
7)How natural was the mechanism which controlled movement through the environment?	.035	23)How involved were you in the virtual environment experience?	-.447
8)How aware were you of events occurring in the real world around you?	-.074	24)How distracting was the control mechanism?	-.169
9)How aware were you of your display and control devices?	-.169	25)How much delay did you experience between your actions and expected outcomes?	-.390
10)How compelling was your sense of objects moving through space?	-.831	26)How quickly did you adjust to the virtual environment experience?	.447
11)How inconsistent or disconnected was the information coming from your various senses?	-.098	27)How proficient in moving and interacting with the virtual environment did you feel at the end of the experience?	.676
12)How much did your experiences in the virtual environment seem consistent with your real-world experiences?	.153	28)How much did the visual display quality interfere or distract you from performing assigned tasks or required activities?	.169
13)Were you able to anticipate what would happen next in response to the actions that you performed	0.000	29)How much did the control devices interfere with the performance of assigned tasks or with other activities?	.247
14)How completely were you able to actively survey or search the environment using vision?	-.218	30)How well could you concentrate on the assigned tasks or required activities rather than on the mechanisms used to perform those tasks or activities?	.247
15)How well could you identify sounds?	0.000	31)Did you learn new techniques that enabled you to improve your performance?	.234
16)How well could you localize sounds?	-.383	32)Were you involved in the experimental task to the extent that you lost track of time?	.204

Figure 2-9: Correlation (R-)Matrix from Factor Analysis of Presence Questionnaire. Each result was compared with the scores of Q1 in the Experience Questionnaire

	Mean	Std.		Mean	Std.
1. Do you ever get extremely involved in projects that are assigned to you by your boss or your instructor, to the exclusion of other tasks?	4.50	.535	16. Do you ever become so involved in a daydream that you are not aware of things happening around you?	2.38	1.188
2. How easily can you switch your attention from the task in which you are currently involved to a new task?	5.38	1.061	17. Do you ever have dreams that are so real that you feel disoriented when you wake?	2.50	1.414
3. How frequently do you get emotionally involved (angry, sad, or happy) in the news stories that you read or hear?	5.00	1.414	18. When playing sports, do you become so involved in the game that you lose track of time?	3.38	1.996
4. How well do you feel today?	5.25	.707	19. Are you easily disturbed when working on a task?	3.75	1.488
5. Do you easily become deeply involved in movies or TV dramas?	4.75	1.035	20. How well do you concentrate on enjoyable activities?	6.00	.926
6. Do you ever become so involved in a television program or book that people have problems getting your attention?	4.25	1.488	21. How often do you play video games? (OFTEN should be taken to mean every day or every two days, on average.)	3.00	2.268
7. How mentally alert do you feel at the present time?	5.13	1.126	22. How well do you concentrate on disagreeable tasks?	4.38	.916
8. Do you ever become so involved in a movie that you are not aware of things happening around you?	3.88	1.458	23. Have you ever gotten excited during a chase or fight scene on TV or in the movies?	4.88	.991
9. How frequently do you find yourself closely identifying with the characters in a story line?	4.38	1.061	24. To what extent have you dwelled on personal problems in the last 48 hours?	3.75	1.165
10. Do you ever become so involved in a video game that it is as if you are inside the game rather than moving a joystick and watching the screen?	2.88	1.959	25. Have you ever gotten scared by something happening on a TV show or in a movie?	4.13	1.553
11. On average, how many books do you read for enjoyment in a month?	2.88	1.246	26. Have you ever remained apprehensive or fearful long after watching a scary movie?	2.88	1.126
13. How physically fit do you feel today?	4.50	.535	27. Do you ever avoid carnival or fairground rides because they are too scary?	2.38	1.996
14. How good are you at blocking out external distractions when you are involved in something	4.88	.835	28. How frequently do you watch TV soap operas or docu-dramas?	2.88	1.553
15. When watching sports, do you ever become so involved in the game that you react as if you were one of the players?	3.63	2.200	29. Do you ever become so involved in doing something that you lose all track of time?	4.38	1.408

Figure 2-10: Means and standard deviations for results from Immersive Tendency Questionnaire

	Q1: Do you play games often?
1. Do you ever get extremely involved in projects that are assigned to you by your boss or your instructor, to the exclusion of other tasks?	-.338
2. How easily can you switch your attention from the task in which you are currently involved to a new task?	.319
3. How frequently do you get emotionally involved (angry, sad, or happy) in the news stories that you read or hear?	-.767
4. How well do you feel today?	.319
5. Do you easily become deeply involved in movies or TV dramas?	.218
6. Do you ever become so involved in a television program or book that people have problems getting your attention?	.455
7. How mentally alert do you feel at the present time?	.662
8. Do you ever become so involved in a movie that you are not aware of things happening around you?	-.325
9. How frequently do you find yourself closely identifying with the characters in a story line?	-.021
10. Do you ever become so involved in a video game that it is as if you are inside the game rather than moving a joystick and watching the screen?	.634
11. On average, how many books do you read for enjoyment in a month?	-.163
13. How physically fit do you feel today?	0.000
14. How good are you at blocking out external distractions when you are involved in something	.081
15. When watching sports, do you ever become so involved in the game that you react as if you were one of the players?	.339
16. Do you ever become so involved in a daydream that you are not aware of things happening around you?	-.247
17. Do you ever have dreams that are so real that you feel disoriented when you wake?	-.128
18. When playing sports, do you become so involved in the game that you lose track of time?	.125
19. Are you easily disturbed when working on a task?	.455
20. How well do you concentrate on enjoyable activities?	.098
21. How often do you play video games? (OFTEN should be taken to mean every day or every two days, on average.)	.956
22. How well do you concentrate on disagreeable tasks?	-.616
23. Have you ever gotten excited during a chase or fight scene on TV or in the movies?	.251
24. To what extent have you dwelled on personal problems in the last 48 hours?	.349
25. Have you ever gotten scared by something happening on a TV show or in a movie?	.247
26. Have you ever remained apprehensive or fearful long after watching a scary movie?	-.341
27. Do you ever avoid carnival or fairground rides because they are too scary?	.079
28. How frequently do you watch TV soap operas or docu-dramas?	-.364
29. Do you ever become so involved in doing something that you lose all track of time?	-.080

Figure 2-11: Correlation (R-)Matrix from Factor Analysis of Immersive Tendency Questionnaire. Each result was compared with the scores of Q1 in the Experience Questionnaire

	Group	Medium	distance	Precaution Question	Approach Vector Q	Distance From QEC	Alignment	Spotted Jet	Spotted Ship
1	Navy	Oculus	70m	Correct	Correct	Correct	Incorrect	No	No
2	Non-Navy	Oculus	70m	Correct	Correct	Incorrect: right	Correct	No	Yes
3	Non-Navy	Oculus	70m	Correct	Correct	Correct	Correct	No	Yes
4	Non-Navy	Oculus	70m	Correct	Correct	Incorrect: right	Correct	Yes	Yes
5	Navy	Oculus	45m	Incorrect: preprig	Correct	Correct	Correct	Yes	Yes
6	Non-Navy	Oculus	45m	Correct	Correct	Correct	Correct	Yes	no
7	Navy	Oculus	45m	Correct	Correct	Correct	Incorrect:	Yes	Yes
8	Navy	Oculus	45m	Incorrect: nothing	Correct	Correct	Incorrect:	Yes	Yes

Figure 2-12: Displays scores for the stages during RAS task

2.7.4 Performance on Task

Figure 2-12 shows the responses to the multiple choice questions, as well as whether the participant spotted the hazards (jet plane and ship in the distance). Results to note include the fact that 3 out of 4 of the navy group incorrectly judged whether the Mars tanker was aligned correctly with the QEC. The precaution question, which asks about the procedures performed before initiating RAS were answered incorrectly by two participants in the Navy group. The distance judgement questions were answered incorrectly by two participants in the non-navy group. It is difficult to infer generalisable results from this as the sample size was very small.

2.7.5 Thematic Analysis

During the parts of the trials where the participant performed the task with the Oculus Rift, video recordings of the trial were taken in order to be orthographically transcribed later [27], where each word is written as it has been said, including moments of hesitation. The camera was facing the participant, with the monitor facing the camera in order to display what the participant was seeing (see figure 2-3).

These transcriptions were then mined for emerging themes, patterns and categories. Using Thematic Analysis [26] which is defined as a method for systematically identifying, organising and offering insight into patterns of meaning (or themes) across a dataset. This method proposes a step-by-step guide for extracting themes from data such as this. The purpose is to identify the most prevalent positive feedback, problems and suggestions for improvement of the experimental task. Each of these observations are sorted in codes which are initially defined by the author. These codes are then sorted in a manner where they become categories and themes. The reason is to provide a scientifically derived justification for categorising the participants' responses. This section catalogues the process behind deriving the final themes and categories.

Transcription Process

The videos were reviewed, with transcriptions made of everything that was said between the participant and the examiner. Transcriptions began from the point in the video when the participant was set up with the Oculus Rift and headphones, and was ready to commence. Certain codes were used within the transcriptions to indicate key events, moments or actions. Examples include: 'Pauses and Looks Around', 'Presents participant with Question 3' or 'Adjusts OR to fit better'. Notes were also made on matters discussed after the video had stopped. This is indicated in the transcripts so as not to cause confusion.

Preparation Before Commencing Thematic Analysis

A decision had to be made at this stage whether to use a completely inductive (bottom-up, i.e. developing codes purely based on the transcripts) or deductive (top-down, i.e. generating codes for extracts based on preset themes or ideas) approach to coding the excerpts within the transcripts. The goal of using thematic analysis was to identify what were the most prominent thoughts and feedback in relation to the experience of VR, controls, and the implementation of the training demo itself. The other aim was to observe whether participants with different backgrounds in gaming and naval experience commented on different themes. However, as this was an experimental test, a predominantly inductive method to coding excerpts was used, as many issues were flagged which may not have been predicted. The generated dataset was expected to be a collection of observations and feedback related to the gameplay experience, Oculus Rift experience and fidelity.

Developing Codes

Codes refer to the lowest level of categorisation, and are closely related to the content of the extracts, e.g. "I had to stop" and "I could not continue, I needed to stop" would fall under the coded "needed to stop". Initial codes were generated according to the topic of certain excerpts which were deemed important. Some of the dialogue, mainly the examiner's comments, were not coded unless they were paired with the participant's answers to give context: e.g. under the code **"Diagram Not Clear"**, an excerpt is entered as

> **Examiner:** If you look on the diagram, particularly on the bottom one. Now I'm not sure but can you see the RAS lines at all on the image?

Participant: No I can't at all. All I can see are the outlines of the ships.

After the initial coding, another pass was done, where codes containing a relatively large number of excerpts (over 8) were split and dispersed into new or existing codes. For example code **"Suggesting Further Procedures in RAS"**, originally containing 19 excerpts, was split into codes such as **"Suggesting Scenario"**, **"Functional Suggestions"**, **"What you should do before RAS"**, **"Would like to go onto deck"** and "**Lack of (human) activity"**. These later helped to identify the emerging theme of **"Suggestions for Future Implementation"**.

Creating Themes

At this stage, all of the generated codes were clustered together according to the themes which emerged from the data. The initial themes were generated at a superficial level, created depending on more functional commonalities, such as issues related to sound, GUI design, controls, motion sickness etc. This criterion was devised by the author semi-deductively, as there were some expectations of which themes may appear, such as the theme of unrealistic animations. Below is the list of themes generated from the first pass:

- Motion Sickness
- Uncomfortable Real-world conditions
- Comment on Controls
- Misleading Reference Diagram
- Issues with GUI
- Realism and Immersion
- Observations
- Unrealistic Animations
- Task Prepardeness
- Suggestion for Future Implementations
- Functionality of Environment
- Distance Judgement

Refining Theme Generation

The next stages of refinement involved minimising overlap between themes. As can be seen by the initial generated themes, most of the excerpts are largely related to the function of the application, as expected. Some of the unexpected/unaccounted for themes included the state of the real-world environment the participant was sitting in and misleading reference diagrams. Some of the themes required sub-themes to be generated in order to fully encompass the variety of reported issues. Further review passes were made in order to refine the categories and create subthemes for more general themes. Thematic Analysis requires that each theme/subtheme generated should be distinguishable from one another, with little-to-no overlap. Figures 2-13 and 2-14 respectively give a break down of final generated themes and subthemes, each accompanied by a definition. The codes are listed and are accompanied by example extracts. There are also frequency counts for each group (navy and non-navy) showing the number of times extracts related to a code were mentioned. Figure 2-15 shows a mindmap of all the themes/subthemes with their associated codes.

Main Theme (MT)	MT Description	Sub Theme (ST)	ST Description	Code	Navy	Non-Navy	Example
Task Preparedness	Comments on how the competent the user perceived themselves as being for carrying out the task given to them.			Confusion about Task	2	0	Which ship am I?
				Wanted more training time for controls and gameplay	2	1	Found it hard to use controller. Got used to it eventually but would have been good to have more time to get used to the controls
				Wanted more training time for RAS	1	2	For people who are not used to this (RAS), give them the material to work through themselves
				Felt 'unqualified' for task	6	3	Needed a better understanding of RAS process. I needed a better briefing because I felt "out-of-my-depth". I was making decisions I felt I wasn't qualified to make
				Familiar With RAS	1	0	Yeah, not the sort of details of the procedures to actually undertake RAS, but I understand the concept of what RAS is and the requirements to span wires across and other things like that
				TOTAL	**12**	**6**	
Realism and Immersion	Comments on the user's self report on how immersed they felt, and what factors contribute to more involved or removed experience. This mostly encompasses technical factors which contributed to their perceived level of immersion	**Visual Fidelity**	Refers to the visual elements which contributed to the user's perceived immersion	Oculus Rift-related Artefacts	0	2	Yeah around the object, around the nose of the QEC, there's a yellow line which is taking up probably 2 pixels? It's taking away from the fidelity
				Performance Issues	1	1	Demo was slowing down
				Demo is good	1	1	It looks very good compared to what I remember of the other one. I mean it seems a lot greater clarity. And the lag is much better from what I remember. Yeah very good
				Realistic	3	1	But yeah it's quite immersive and quite realistic
				Needs higher fidelity	0	1	There needs to be a higher fidelity of console controls, where the fidelity on the QEC could be reduced
				Find it immersive	2	1	It's very cool, I do like the way you can look around and it's quite free.
				Character too tall	0	2	I'd also just check this height because it feels like I'm going to wack my head off the top
				TOTAL	**7**	**9**	
		Environment	Refers to the functionality game world factors which contribute to the user's perceived presence.	Sound attenuation too sharp	0	2	Sound change needs to be more gradual, and there also needs to be more ambient sounds present
				Lack of 3D sound	1	1	There should be more pin-pointable sounds, like the sound of the jet flying by.
				Fog too dense	1	1	Yeah in terms of granularity that to me, it had the same impression of something appearing out of fog. Because of the size of it, it appeared at a closer range than I would have expected it to appear in good conditions.
				Lack of human activity	7	0	There doesn't appear to be anybody about down on the deck
				Angle of RAS hose	3	1	Looking at it now the angle doesn't look quite right from the hose perspective
				TOTAL	**12**	**5**	
		Unrealistic Animation	Refers to the problems which users identified in the animations of major components, i.e. the animated behaviour of the ships, and the animation of the avatar.	Tanker approaching too fast	4	2	I'm not sure if that's a realistic speed but it strikes me as being very fast in terms of relative speed of the carrier etc. I'd be twitched
				Correction angle to steep	0	1	Quite a steep angle to come in at
				Unrealistic ship animation	7	0	I mean when we slowed down and stopped it was all a bit too perfect. I'd be expecting us to be jossling for position; moving backwards and forwards and all the rest of it. It's almost in perfect sync. I'm sure there'd be some pitching and yawing and, you know, general movement going on, where you're always worried about whether that's sort of a bit of natural motion and turbulence, or whether you're finding something more sinister. It's all a bit too perfect and still unaligned
				Unrealistic animations (other)	1	1	Just simple movement of leavers. It looks good. I can definitely see the benefit of what this could bring
				Unrealistic body animations	0	1	Body and animations need to be improved.
				TOTAL	**12**	**5**	
		Distance Judgement	Refers to observations users had about the distance judgement part of the task. Specifically, these are comments related to the ability of the user to perform this task based on their own expertise and experience, and using the Oculus Rift environment to do so.	Oculus Rift helped with alignment judgement	0	1	I think the Oculus Rift really helped out with judging the alignment
				Used prior knowledge for distance judgement	1	1	I managed to work out the distance between QEC and MARS based on prior knowledge of QEC
				Difficulty with judging distances	1	1	OK well I'm back to saying that I don't have enough experience to make an accurate judgment, but I think we're too close. Maybe, because I'm not used to the sheer size of QEC.
				Used ship width for distance judgement	2	2	I guess the reference I was using there was I would looks at, I'd say, the width of MARS and look at the gap, and assuming the MARS isn't 25 metres wide, which I don't think it is, the gap looks maybe 1.5, to 1.75, maybe even two MARS' wide
				TOTAL	**4**	**5**	

Figure 2-13: Table showing themes and subthemes generated through thematic analysis. Each theme/subtheme contains a list of codes associated with it, along with example extracts.

Main Theme (MT)	MT Description	Sub Theme (ST)	ST Description	Code	Navy	Non-Navy	Example
Observations	This theme encompasses codes which related to observations which the user makes relating the task.			Observations and Misc	3	0	The hydrodynamics of the QEC could cause issues with the MARs tanker
				Noticed jet	5	3	Erm slightly concerned about that aircraft still taking off.
				Saw ship in the distance	6	9	But again other than that ship in the front, there's nothing that would particularly trouble me
				Oblivious to jet	0	2	Oh. Well, it did cross my mind; I just thought it was part of the demo
				TOTAL	**14**	**14**	
Player Discomfort	This describes factors relating to the user's physical discomfort. These are due to the effects of simulation sickness induced by the hardware itself or the implementation of the player movement			General motion sickness	0	1	Yeah it makes me feel a little bit sick, getting a bit of motion sickness
				Strafing does not feel natural	0	4	It's funny, when I stop...if I strafe to the left and I stop, my body wants to continue going a little bit. You know that sort of (motion) like if you did it in real life. So if I strafe to the left and stop, normally if you're doing that motion physically your body would react to it. It feels a little bit funny on the brain when do that
				Motion sickness from rotating body with controller	0	1	Makes my eyes go a bit funny when you spin the joystick. It's kind of blurry. [[pause]] It's better when I move my head actually. It's when I move it with the stick... Yeah it's better to look around
				Room too warm	0	2	Room was too hot, needed ventilation.
				TOTAL	**0**	**8**	
Suggestion for Future Implementation	The codes in this theme relate to suggestions for any future implementations in terms of scenario, gameplay and design			What you should do before RAS	6	0	The rig preparation would start probably well in advance if those were the procedures. But it would not be complete until the complete transfer of equipment to QEC. So the safety officer would check the bridge equipment which I believe would be under 'prepare rig'. He may do that the day before the RAS is going to take place
				Functional Suggestions	3	3	Maybe use a narrator/in-game tutorial system
				Suggesting Scenarios	5	2	You should add a scenario where the ships begin to drift into or away from each other. and see if the player notices
				Would like to go onto deck	0	2	Can I actually go down onto the deck?
				Would abort RAS after seeing ship	3	0	There's an obstacle ahead, I can't see what it is at this point in time. At this stage I would abort the mission
				Would like more control in gameplay	1	2	I felt like I was going to be doing more of the controlling
				Task was too slow-paced	0	1	Would like to see future tests more fast-paced
				Task was too fast	0	1	The entire trial was presented quite quickly
				TOTAL	**18**	**11**	
Functionality	This key theme encompassed factors which relate to the functionality of the implementation	**Issues with GUI**	Relating to issues with the in-game UI for showing hints and questions	UI is pointless	0	1	Not quite sure why the menu was there, but I would have liked to have had control of it.
				Would like more control over UI	0	5	I quite liked the way the questions popped up. It might be nice to have some way to press a button and bring up a question or you know interact with it. So maybe select 'up' 'down', and hit 'X' (on the controller) to confirm your question response. Obviously that would be better if I wasn't speaking to you
				GUI is blurry	2	2	It's all very blurred but that might be my eye sight
				GUI placement	1	0	GUI was too far to the left. Maybe it should be right-aligned
				TOTAL	**3**	**8**	
		Misleading Reference Diagrams	Relating to issues where the user found the diagrams showing the ship positions to be misleading. This was either because the diagrams did not appear to match with each other, or with the main world representation	Diagram not clear	1	1	Me: If you look on the diagram, particularly on the bottom one. Now I'm not sure but can you see the RAS lines at all on the image?P: No I can't at all. All I can see are the outlines of the ships
				Mismatch between diagrams	0	1	I'm not sure... [[Pause]]... The problem I have is that in the top image it looks like we're at that distance, but in the bottom image, the top down image it looks like we're closer. SO I'd say we're about right
				Diagram(s) to world mismatch	1	4	Again images made life too difficult. Trying to reconcile 3 images as one.
				TOTAL	**2**	**6**	
		Comments on Controls	Relating to issues with control mechanisms of the controller and the first-person implementation	Strafing does not feel natural	0	4	It's funny, when I stop...if I strafe to the left and I stop, my body wants to continue going a little bit. You know that sort of (motion) like if you did it in real life. So if I strafe to the left and stop, normally if you're doing that motion physically your body would react to it. It feels a little bit funny on the brain when do that
				Motion sickness from rotating body with controller	0	1	Makes my eyes go a bit funny when you spin the joystick. It's kind of blurry. [[pause]] It's better when I move my head actually. It's when I move it with the stick... Yeah it's better to look around
				Difficulty with controls	5	1	P: So if I push that to the left that's my head? Me: No that's your body. That stick is more body position rather head position. P: Ah ok. Me: Right stick is body rotation.
				Like controller	2	0	I like the way that you can look around and you can turn with the controller, and then look further.
				Character too tall	0	2	I'd also just check this height because it feels like I'm going to wack my head off the top
				TOTAL	**7**	**8**	

Figure 2-14: Table showing themes and subthemes generated through thematic analysis. Each theme/subtheme contains a list of codes associated with it, along with example extracts.

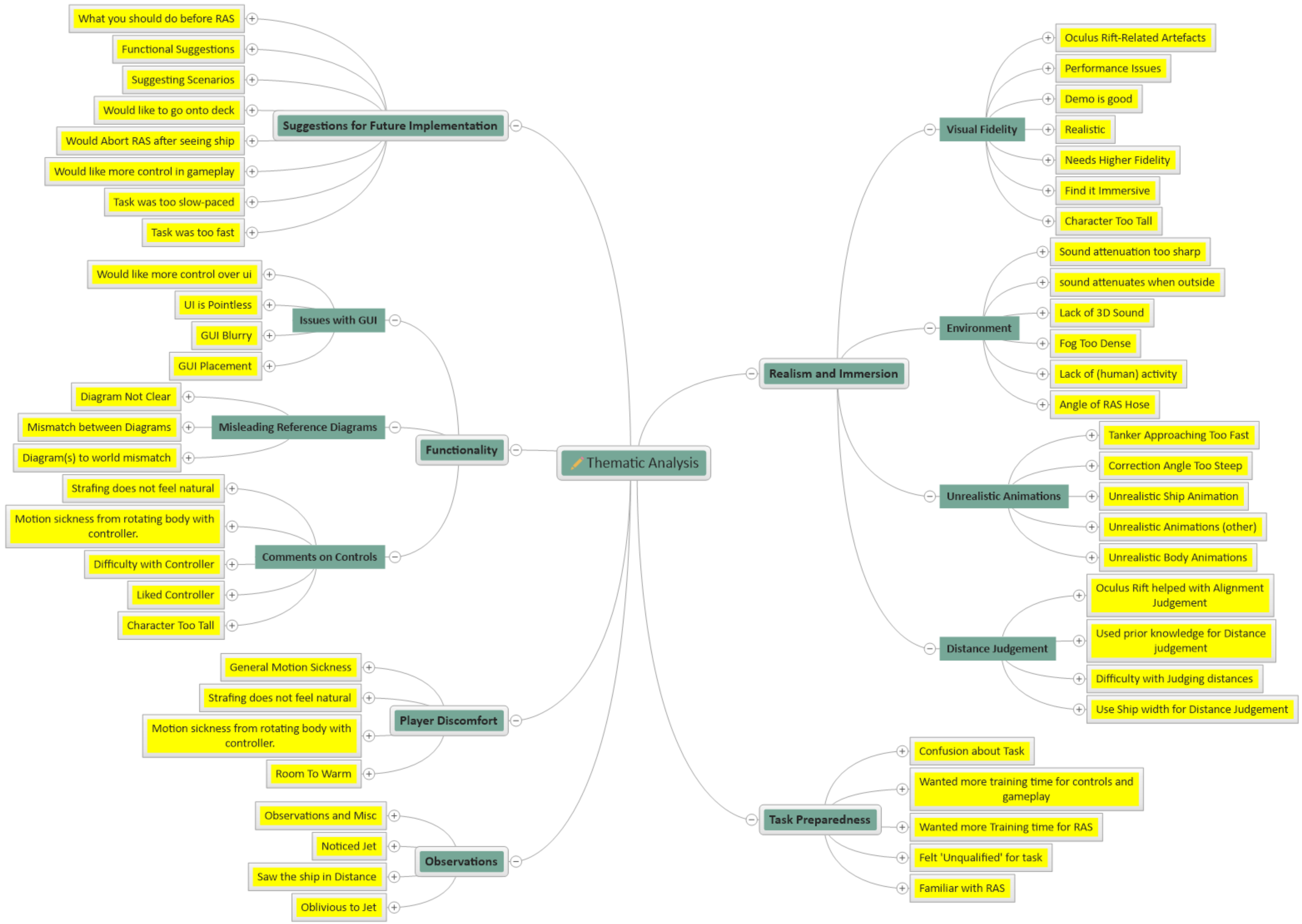


Figure 2-15: Illustrated map of themes and associated codes

2.7.6 Conclusion

The analysis of these trials highlighted many issues in designing a VR application as a training tool. While presence scores were generally mid-to-high, there were issues such as the implementation of UI and bad animations which overshadowed the participants' ability to perform the task. The ITQ did not yield any useful results with regards to future studies. Thematic analysis showed that there were differences in focus on what the issues were. Non-navy participants tended to comment more on functional and gameplay shortfalls, whereas the navy group focussed more on the logic of the gameplay, animation of ships and lack of human activity. Motion sickness was not as great an issue for navy participants as it was for non-navy. Reports of motion sickness mostly occurred as the result of moving the first-person avatar, not ship movements or head movements. Though no trials were terminated as a result of sickness, it was still an issue worth investigating in further studies as there were a low participant number and limited interactivity in this virtual environment.

2.8 Discussion

The purpose of this study was to observe how suitable the developed task was for experimentation in an attempt to show where immersive HMDs such as the Oculus Rift could benefit naval training. The results show where feedback varies depending on expertise, i.e. the navy group focussed more on the realism of scenario and VE, and the non-navy/gaming group focused on functionality and gameplay. The design and analysis of task performance was overshadowed by technical issues with reference diagrams, the method of answering questions, and a general reporting of feeling under-qualified due to lack of background knowledge.

2.8.1 Participants

One of the main shortfalls of this study was the sample size. Without greater numbers of participants, it is hard to generalise some of the observed results. These participants were chosen by the supervisor based on their known expertise. Therefore the divide in results from the Experience Questionnaire was expected. Another issue was that for the purpose of this test, all of the participants were at least somewhat familiar with this project, in particular, the RAS simulation which was developed. This study would have to be replicated or extended with more participants (unfamiliar with the project) for more robust conclusions to be drawn.

2.8.2 Experimental Method

At the end of the trials, the participants were asked for their feedback on the experimental method. This included feedback on the implementation of the experimental trial and the VR software. It was clear from the feedback (i.e. the 'Task Preparedness' theme) that more time for training was required. A lot more background on the RAS process needed to be given to both groups. Although the implemented task was a simplified overview, there were still too many things to consider. The task itself should be outlined in a more explicit way. For example, for spotting obstacles and hazards the instructions should state that the tanker would never approach, or would abort an approach if there were any obstacles or hazards like the ship in the distance, or the jet taking off and landing (see figure 2-6 on page 27). Some (from the non-navy group) suggested using and in-game tutorial and feedback system e.g. an ever-present checklist of tasks, or a narrator system.

Additional training should have been provided at the start of the trial for familiarising participants in navigating the virtual world. In the navy group, in particular, there were problems with familiarisation with the controls. Due to time constraints, the trial had to continue, with some reporting that their concentration was too focussed on the controller. Users in future implementations should be placed into a sparse virtual environment, or a simplified version of the main experimental environment to practice using the controller before they begin the actual experimental task.

2.8.3 Experimental Environment

One of the most noticeable results was the difference in feedback between the two groups when it came to the environment. Much of the criticism from the non-navy group pertained more to the functionality of the gameplay, e.g. interaction with the world user-interface, and sound design. The most noticeable theme to show this was 'Player Discomfort', where all of the codes came from feedback from the non-navy group. This is corroborated with the result from the experience questionnaire showing that there was higher reported susceptibility to VR sickness in the non-navy group. This indicates naval experience might help to mitigate this effect. They can be used as control subjects to measure against when considering designing VR experiences with a high chance of inducing VR sickness. In summary, there was a greater focus in psychological fidelity from the non-navy/gamer group. In contrast, the navy group tended to report more on issues relating to the physical fidelity of the simulation. The unrealistic animations and behaviours of the ship were frequently mentioned in their feedback. As expected, a great many comments and codes were related to the environment, procedures and suggestions for scenarios.

2.8.4 Performance on Task

There was no formal analysis of performance on tasks done. However, some of the incorrect answers are explained by the results from thematic analysis. The questions relating to precautions to take before initiating RAS were answered incorrectly by two participants in the navy group. The results from thematic analysis suggest that this may have been due to lack of activity in the simulation, and lack of definition of scope. For example, one participant who answered this incorrectly believed 'prepare rig' referred to a procedure which occurs prior to the events of the demonstration. See quote below, which exemplifies flaws in the logic of the application which would have negatively influenced the results from the task questions.

> **Participant:** "The rig preparation would start probably well in advance if those were the procedures. But it would not be complete until the complete transfer of equipment to QEC [occurred]. So the safety officer would check the bridge equipment which I believe would be under prepare rig. He may do that the day before the RAS is going to take place"

In future implementations it may be better to simplify the tasks, which while still within a naval training context, may be easier to analyse and be better differentiators of performance. The Task Preparedness theme shows that some of the participants felt unprepared or under-qualified for the task. There were also many functional and scenario-related problems reported by all participants which undermined the validity of the performance results.

2.8.5 Implications

From a design standpoint, this study was flawed. However, the most useful results came from performing Thematic analysis on the transcripts. The issues most associated with the HMD (OR) were related to locomotion in the VE, i.e. moving and rotating the first-person avatar. Those who had used HMDs/OR before still reported sickness as a result of using it, whereas the navy group, who had little-to-no HMD/OR experience had lower amounts of reported sickness. Their concerns were mostly with design of the training scenario, i.e. ship animation, procedures, lack of non-player characters etc.

The scope of the tasks for VR application testing needed to be scaled back, particularly as non-naval applications were being considered for future experiments. During the stage of the doctorate timeline, the department was considering projects which were both pan-defence and non-defence. It is difficult to infer any solid results from this study based on task performance being related to presence. Tasks should be restricted to more specific actions designed to take advantage of HMDs. For example, the distance judgement and alignment tasks should be fleshed out into a more robust experiment. The two ships could drift towards each other during the transference of fuel. The test could be one whether the participant is aware of its occurrence.

This study needs a lot more development before it could be used to evaluate immersive HMDs as a viable option for training. The author considered changing the scope of the research to a more specific problem regarding usability. Rather than trying to evaluate their use in specific types of training like RAS, the research should focus on more general types of training or different kinds of platforms and environments. For example, standard operating procedures in an engine room vs on the bridge of a tanker, where they are contrasting environments, i.e. open vs close-quarter.

To conclude, this study yielded a null result, in that there was no clear way of indicating whether presence or use of HMD improved training experience. It gave some insight into what the different priorities and issues navy and non-navy observed in the tests. However, the low participant numbers means that implications are not entirely robust. Changing the scope of research from scenario-specific tasks to more general settings (like bridge and engine room) was therefore considered for future study.

Chapter 3

VR Sickness, a Significant Barrier

This chapter gives an overview of the shift in research focus onto VR Sickness. Development of VR training applications at the partner company was increasing in visual and functional complexity. This presented new obstacles in designing VR applications for consumer HMDs at the time, which included increased scene complexity and character movements and interactions. These obstacles were identified while developing VR applications designed to use immersive HMDs in training. Problems began presenting themselves when observing the induction of VR sickness through simulating near-realistic body movements or when the VE was based in a busy setting. These observations were based on users trying the applications during testing and demonstration sessions.

3.1 Motivation

BMT was developing the "Engage" platform; a virtual reality framework for developing virtual training applications. The main aim of "Engage" was to be able to provide a framework for portable VR training solutions. Training provided would aim to reduce training burden and required onboard training time. VR applications where navigation via character movement is required in the VE while being physically static (i.e. sat down) have inherent problems primarily including the induction of VR sickness [13, 1, 10]. While the user is sitting down and controlling his/her avatar with a game controller, there is a sensory mismatch between the first-person avatar's movement and the user's own (lack of) body movement [29]. While there are solutions for accurately simulating locomotion and body movement in the virtual world, such as full body motion capture and omnidirectional treadmills, the aim of this work was to provide a portable solution. Within the context of this research, a portable VR solution should only require a HMD, controller and preferably a laptop or small personal computer. The purpose of this is to be able to provide VR training in areas with limited space, such as onboard a naval platform. While in chapter 2, participants with naval experience did not demonstrate susceptibility to VR sickness, those results were underpowered and warranted further study. Furthermore, the applications being developed at BMT were branching outside of the field of naval training. Therefore it was of interest to develop a general solution which could be applied to any VR training applications in order to reduce VR sickness. Software-based approaches to achieve this became the topic of subsequent studies.

A VR creation tool was also being developed which allowed for interaction between multiple users, particularly trainers communicating with students (cross-platform i.e. trainer interacting with and monitoring VR student via tablet/web interface). Many of these applications were basing functionality on gameplay designs found in typical first-person applications, i.e. an avatar has a mounted virtual camera, whose actions are determined by physics-based motion [30], which allow for a more realistic representation of human movement. Another key feature was the inclusion of transitional animations, which are triggered by the user when they wish to interact with something, e.g. sitting on a chair or opening a door. In typical first-person applications, there are many camera techniques used to simulate realistic effects of motion, such as camera shake, head-bobbing and screen distortion [31].

Problems arose when many of these same techniques were applied to an immersive HMD camera. During tests and demonstrations of VR applications, there were reports of sickness when the user moved the character, especially when rotating on the spot [31]. At the time, head-bobbing was artificially applied to the camera when the character was moved. This resulted in realistic but uncomfortable movements. As the camera movement does not directly correspond to the user's head movements, the disconnect between the user's body movement and the avatar movement is exaggerated by the fact the user expects to have direct control over the camera movement. The same problem arose when implementing transitional animations. While other applications currently strip away character avatars or complex movements to mitigate this problem [2], scenarios being simulated by the sponsor company required this level of realism. In hindsight, this need was slowly mitigated by the introduction of new interaction peripherals and room-scale VR. VR applications which needed some realistic representation of human movement were mostly implemented as room-scale VR applications. However, there was still a need for a facilitating vection in static VR setups such as seated and/or mobile VR applications.

The goal of this research was to identify key factors which induce VR sickness that need to be reduced, which were specific to the problem of providing a realistic 'sit-down' experience. This would allow the user to become familiar with crucial procedures without the distracting discomfort caused by using these types of immersive HMDs. While some of these factors could be mitigated by upgraded hardware i.e. higher refresh rate and under 20ms motion-to-photon latency [32, 33, 34, 35, 36], the focus of this is study is to look at different image presentation and gameplay techniques, e.g. camera transforms, field-of-view manipulation and character perspective. These aspects are common in designing games and other applications. They are also factors which are simple to manipulate and test.

3.2 Literature Review

3.2.1 VR Sickness

Many tangible causes of VR sickness come from problems such as vergence and eye distance in stereoscopic viewing modes [7, 8], latency and image quality. Many of the other influential factors are explained in detail by research into the vestibular system, and cue-conflict theory which occurs when the perceived movement is different from the exerted force on the rest of the body [9, 10, 11]. Symptoms of VR sickness include headaches, stomach awareness, nausea, vomiting, pallor, seating, fatigue, drowsiness and disorientation [12]. While some of the issues can be solved by upgrades to hardware (e.g. HMDs with better resolution and/or lower latency [33]), there are other influences which need to be addressed within the implementation of VR applications. Most of the studies mentioned in this section evaluate levels of VR sickness through self-report questionnaires, i.e. the Simulator Sickness Questionnaire [37, 38, 39].

3.2.2 Image Scaling

There are a number of factors which can influence the induction of VR sickness. A study conducted by Moss & Muth (2011) [13] looked at manipulating image scale, field-of-view, latency and peripheral vision in order to determine which, if any, resulted in more reports of VR sickness. The FOV was defined as a combination of display field-of-view (DFOV), the field of view afforded by the physical display, i.e. screen size, and geometric field of view (GFOV). Therefore, image-scaling refers to the ratio between GFOV and DFOV [34, 40]. Ideally, this should be a one-to-one ratio for the best result. In addition, participants in the study by Moss & Muth (2011) [13] were given the option to grip a handrail for support. The experimenters manipulated scale magnification (scale factor of 2) and minification (scale factor of 0.88) to see if it would have any effect on VR sickness. The results showed that most of these factors (including the handrail) did not have a significant impact on reported VR sickness. The biggest impact on sickness was from completely occluding peripheral vision (i.e. fully immersive headset). When the participant was fully immersed, with no view of the real world (like with the Oculus Rift), it greatly accentuated the effects of image scaling and latency on VR sickness. Moss & Muth [13] concluded that in order to reduce sensory mismatch, peripheral vision of real the world should not be blocked. This is not a possibility for the author's current research. This does however highlight the problem of image scaling being more present in this condition.

Image scaling is also a big contributor to the illusion of self-motion and vection [41]. A paper by Bles & Wetheim (2001) [42] discusses the particular problems faced in military simulators with regards to VR sickness. They give examples of ship-motion simulators. While also identifying image-scaling and latency as big influence, they give greater importance to vertical sensory mismatch, where the conflicting perception of gravitational forces is one the biggest contributing factors. However, this study utilised a Proview HMD, which has a much smaller FOV compared with current consumer HMDs, as well as running on older hardware. This could result in higher elicitation of VR sickness compared with modern consumer HMDs such as the Oculus Rift DK1.

Rebelo et al (2012) [43] proposed that a more ecologically valid way of testing UX (User Experience) design can be achieved using virtual reality. As part of this research, they outline some of the advantages and caveats which come by using VR as this kind of platform. While they mention immersiveness coupled with image scaling and latency results in increased VR sickness, they also outline system design and navigation as a means of reducing VR sickness. In particular, head-based navigation (direction of travel effected by head rotation) is outlined as being a contributing factor to VR sickness. They also identify scene complexity (detail, clutter, business of the virtual environment) [44, 45] as a potentially limiting factor. No study had been able to conclude that the rate of visual flow has a definite impact on VR sickness.

3.2.3 Optic Flow and Locomotion

The influence of optic flow [46] on VR sickness has been studied alongside the influence of vection and self-motion. Diels, Ukai and Howarth (2007)[47] showed that increasing radial optic flow by 20% of the control condition did result in increased VR sickness. They found this had a greater effect on the peripheral vision of the participant's gaze rather than in the centre of their visual field. This suggests that increasing optic flow in the peripheral visual field notably contributes more to VR sickness than increasing optic flow in the central visual field. This is why in the following sections there is a strong focus on the dynamic constriction of the FOV to reduce VR sickness.

Studies by Bubka, Bonato & Palmisano (2007)[48], Smart Jr et al. (2014)[49] and Gavgani, Hodgson & Nalivaiko (2016)[50] looked at the influence of optical flow direction on VR sickness. By varying the flow direction and intensity, it was observed that VR sickness was induced as a result of participants' expectations and sensory mismatch in the vestibular system. These are the same problems found when continuously rotating a virtual avatar. This is why VR applications at the time implemented "comfort mode" turning by incrementing character rotations by 30 degrees [31].

Studies such as Line et al. (2002)[51] and Sparto et al. (2004)[52] found that an increased FOV results in greater reports of VR sickness. In the study by [51], each participant was subjected to 4 different FOV settings (60, 100, 140 and 180 degrees). They measured both VR sickness and their sense of immersion. The results showed that while an increased FOV did increase levels of immersion, it also increased reported VR sickness. The reduction in sense of presence presents a barrier to the method for reducing VR sickness [53]. Though this is an important find, it may not necessarily extend to modern immersive HMD-based applications (as this study was also conducted back in 2001). Methods for dynamically reducing FOV have been tested. Kim et al. (2008) [54] use biological readings (electrophysiological inputs as a result of simulator sickness) of participants to narrow the FOV and also reduce the acceleration of movement when the readings were showing signs that participants were suffering VR sickness. This reduction however did reduce the participants' sense of presence. Though vection alone may not be the root cause of VR sickness it can potentially amplify the effects of optic flow on VR sickness [29].

A salient problem for the author to address was the ease of locomotion in the virtual world while in a seated position, which would minimise induction of VR sickness [29]. Llorach & Blat (2014) [5] compared two modalities of locomotion using the Oculus Rift Development Kit 1; positional tracking and traditional PC game controller. Their results showed that there was no significant impact on presence, however VR sickness was reduced as a result of positional tracking. They also outline some other potentially influential factors which include the limitations imposed by the controller input condition (reliance on touch and knowledge of the controller layout as they cannot see game controller, learning curve and cognitive load). This is reinforced by the author's own research, where many users of the author's virtual reality demonstrations complained that the turning ability was too fast, and not adjustable, which provided a barrier to usability.

3.2.4 Exposure

It is important that for the types of simulations being developed at the partner company, the user is able to remain in the virtual training environment for an extended period of time (over 10 minutes). Very few studies had been done with modern immersive HMDs at the time of writing. Steinicke & Bruder (2014) [55] evaluated the long-term use of the Oculus Rift DK1, by subjecting a participant to 2-hour blocks within the virtual space, in an optically tracked room where physical objects like furniture were tracked and replicated in the virtual space to provide passive tactile feedback. The participant was tracked with IR markers. In total the participant spent 24 hours in simulation, during which time metrics (Simulator Sickness and Presence Questionnaires) were recorded to evaluate the effects of this kind of repeated exposure [56]. The user also engaged in activities such as watching movies, listening to audiobooks and "visiting an island". The reported VR sickness was relatively lower than expected and was reduced with exposure over time. Much of the difficulty came from issues associated with the Oculus Rift DK1 (i.e. latency issues in computationally demanding situations and eyes drying out due to enclosed visual field). The study showed that it was possible to spend a considerable time in the virtual world. While this is a useful insight, there are major differences between this and the author's current research. Mainly, the user in this study[55] was tracked and able to walk around freely in a relatively sedate environment which did not require much mental load. For the author's project, studies need to be done on exposure in more demanding environments like in the close-quarter simulations being developed at the partner company. As the current research is using the Oculus Rift DK2, it should mitigate some of the physical discomfort experienced in Steinicke & Bruder's research[55].

3.2.5 Summary

The illusion of locomotion without the expected inertial forces on the body leads to discomfort [9, 10, 11]. While there are solutions for accurately simulating locomotion and body movement in the virtual world, such as full body motion capture and omnidirectional treadmills [57], the aim of this work is to investigate design approaches that work for static workstation set-ups. Therefore it will need to identify and mitigate the factors which contribute to VR sickness. In order to try and develop a hardware-agnostic method, it was believed that developing methods centred around adjusting GUI and camera design would be practical. This includes manipulating camera perspectives, field-of-view adjustment and priming via UI. As demonstrated in the above studies, reducing the FOV (and therefore peripheral optic flow) should help considerably in reducing VR sickness. The aim was to do this without reducing the users' sense of presence. The methodologies outlined in the next section are different approaches to achieving this.

3.3 Proposal

Prior to the final two studies on dynamic field-of-view constriction, this proposal was written in order to convey the rationale behind this method. Another method is highlighted in the section (changing camera perspective). However, this is not pursued in this thesis as it was decided by the author that it was better to focus on the DFOV constriction method. There was more literature (highlighted in the previous section) showing that constricting FOV can help to reduce VR sickness.

Given that some of the highest influences on VR sickness are the occlusion of peripheral vision (fully enclosed and immersive HMD where real-world view is blocked) and a wide field of view (greater than 90 degrees), both found within the types of immersive HMDs being used in this project, a method for reducing the impact of this during more intense activities in the virtual world needed to be developed. Removing the occlusion of peripheral vision was not possible with the hardware being used. While increased exposure and predisposition to countering the effects due to prior experience and training (in the navy) would help to mitigate these effects, many actions in the training being developed would still cause significant discomfort during trials and demonstrations (caused by locomotion). Therefore the focus remained on adjusting the camera display FOV in-game during more intense and busy situations [49, 45] such as transitional animations (i.e. an animation where the character sits on a chair would cause discomfort during demonstrations). The FOV would be altered using vignetting effects rather changing the camera properties. It was proposed that a number of methods are investigated as potential solutions for minimising VR sickness during transitional animations and rapid or complex character/camera movements. The goal was to identify a method or pipeline of methods which would be most effective for training in complex virtual spaces without the ability to physically walk around and with only the ability to directly translate head position and rotation into the virtual world.

Dynamically adjusting FOV on a continuous scale: During transitional animations or rapid movements, the FOV could be adjusted to replicate a similar 'letter-boxing' effect as those which occur in video-game cut-scenes. This could act both as a way of reducing the number of conflicting factors on screen, and as a priming tool for participants as a way to consciously but subtly informing the user that the camera is about to be moved in a way that is not completely consistent with their head and body movements. This would be similar to a 'blacking out' or 'losing consciousness' effect found in many first-person games, where a darker texture 'bleeds' in from the borders of the camera view (see figure 3-2).

Changing camera perspective: When a transitional animation occurs, the user's camera could fade out then fade into a new view; showing their avatar performing the action, e.g. opening doors, sitting down. This could be from a third-person 'over-the-shoulder' perspective, or a different camera angle depending on the action (see figure 3-3).

3.4 Overview of Proposed Trial Design

This section outlines a trial design which could be utilised in future studies during the EngD timeline. The tests would consist of a number of activities, based on simplified versions of tasks currently being implemented for real training simulations. While it would be in a similar virtual environment, the tasks would be singular and minimal, but designed to test a wide range of animations and scenarios. Tasks include:

- Walking around the room while turning as quickly as possible
- Interact with objects to engage transitional animations such as opening doors, sitting in chairs, pulling levers, turning valves etc.
- Experience reactive animations, such as the character avatar falling over

The task would be designed in a way where it requires no knowledge of the virtual platform. The setting was in order to replicate the visual complexity which will be presenting the training simulations. Expected differences in performance should therefore be observed due to susceptibility to VR and motion sickness, and experience with navigating virtual worlds with a game controller.

Each trial would vary depending on which features are activated:

- No features activated; camera view is unaltered throughout

- Constricting FOV via vignetting. Levels of adjustment (FOV reduction amount) and frequency of adjustment (situations in which FOV is adjusted) can be varied to add additional levels of testing

- Using camera switching to change camera perspective during transitional animations. Additional levels could be added by exploring different camera perspectives to switch into (e.g. over-the-shoulder camera perspective)

While a controller-less option has been considered, based on previous research and results from the author's experiments, relinquishing control completely from the user would be counter-productive for the research (see Chapter 2). It is currently being considered whether some of the trials could be controlled entirely automatically or by the experimenter.

3.5 Methodology

Two methodologies are proposed; vignetting and camera perspective change. Each modality will be tested in separate experimentation sessions. The procedures the user is required to perform will be consistent across both sets of experiments. A baseline comparison condition will be present in both experiments, where the camera is unaltered. Due to the stage in the EngD timeline at this point, it was difficult to focus or develop other methodologies. Eventually on one potential method was pursued.

3.5.1 Measures

Each participant will be issued a variant of the Simulator Sickness Questionnaire (SSQ) [37] and the Experience Questionnaire (which will be adjusted to reflect more on experience with virtual world interactions). Just as in the previous study, each trial will be recorded and transcribed for analysis.

3.5.2 Task

Each participant will be required to use the immersive HMD in all conditions. They will each be issued with the experience questionnaire before the trial begins, and the SSQ when the trial ends. When beginning the task, the participant will need to move a first-person avatar around an enclosed virtual environment modelled to look like an engine room. They will initially be allowed to move around freely within the virtual

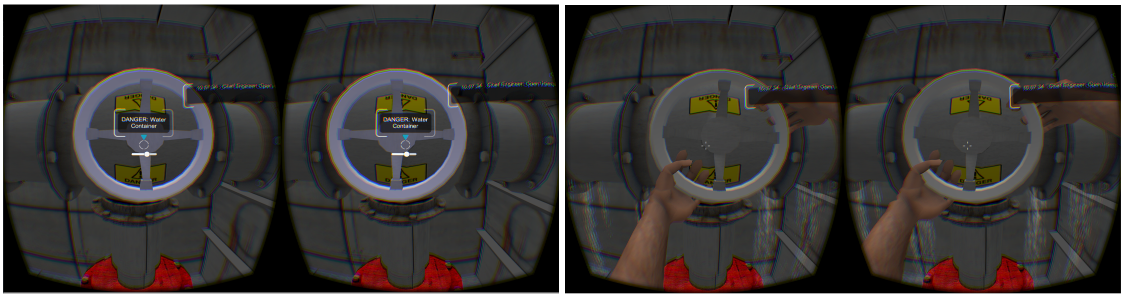


Figure 3-1: Screen shots of triggering valve-turn animation (left) and the animation itself (right)

world until the participant feels they are comfortable to continue and become familiar with the controls.

Participants will then be asked to complete a series of short tasks. These will be designed to cover a range of uncontrolled movements where the user will not be able to fully control the camera with their head movements. They will begin with moving to different checkpoints around the virtual room as quickly as possible. These will require quick rotation movements. This is followed by a series of tasks which trigger transitional animations, where a user will be directed to sit on a chair, interact with the valve (figure 3-1) and open a door. Finally, they will be informed that they can walk around freely for one more minute, at which point the experimenter will trigger an animation which will cause the users' avatar to fall over and get up again.

3.5.3 Vignetting Experiment

The vignetting effect will be used to mask the edges of the camera view by adding a blackened border around the whole view. See an example of vignetting in figure 3-2. This effect will be activated (gradually reducing FOV over time) when the camera is rotated beyond a minimum speed set by the experimenter. It also activates when the user triggers a transitional animation. The maximum percentage of screen space will be set to approximately 30 per cent (70 degrees horizontal FOV). This means that the black-border effect will cover at most 30 per cent of the screen by area. While in future trials this value will be adjusted, this value will remain consistent for the first round of experiments. Another variable will be the rate of constriction, which determines how much the border effect increases over time while the camera is rotated at a certain speed. For the first round of experiments, the values will also be kept consistent.

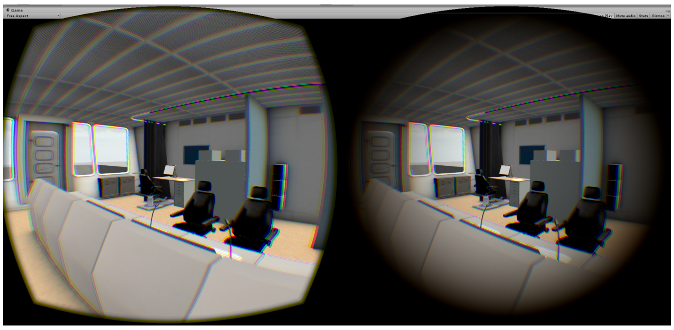


Figure 3-2: An example of the Vignetting effect. The left image shows the unaltered OR view. The right image shows the OR view after partial Vignetting

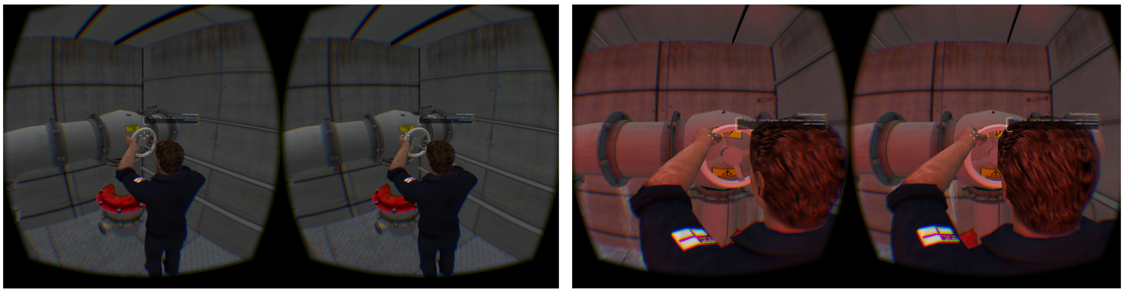


Figure 3-3: Screen shots taken from two potential 3rd person camera views during a transitional animation

3.5.4 Perspective Change Experiment

The perspective change refers to changing the camera view from a first-person to a third-person/observer perspective during transitional animations (see figure 3-3). When the user triggers an event, the view will fade out and fade back into the new camera view. This will be at a fixed point, looking from above and behind the shoulder. They will still be able to move the camera with their head movements, as well as lean. Once the action has been completed, the camera will then fade out and fade back into the first person perspective. Figure 3-3 shows two of the potential camera angle anchors.

3.6 Ethical Considerations

Prior to the session, each participant who would like to participate will be briefed on what the task involves. They will be informed that they will be wearing a HMD, which allows them to view a virtual environment in 3D. The brief will provide a warning that using the VR application may cause some feelings of discomfort and that they are free to withdraw from the experiment at any time. The experimenter will be present at all times and will constantly observe the participant for any signs of physical discomfort (paleness, sweating, heavy breathing, visible light-headedness or stomach pain). At that stage, the author was responsible for discontinuing the experiment. In the author's experience, few participants continue to use the OR regardless of physical strain. All data from questionnaires and video will remain anonymous, and the participant can withdraw themselves from the study at any time.

3.7 Conclusion

The proposed study shifted focus from the analysis of performing certain training with immersive HMDs to the usability of these HMDs with the complex scenarios being developed at the sponsoring company. In particular, this research recognised the need to mitigate induction of VR sickness, which can be caused by the more complex and rapid avatar animations which are required in the simulations. While many of these influential factors can and will be addressed with hardware and firmware upgrades, there were methods which needed to be implemented on the software side to aid the user in remaining engaged during more sporadic camera movements. This research looked at adjusting the FOV dynamically during certain intense animation events, and assess the use of camera-perspective changes to ease the user experience. These methods were to be assessed for impact on ease of usability by analysing participant feedback on the SSQs and transcriptions of their comments throughout the trial.

Chapter 4

Dynamic FOV Constriction: A New Approach to Controlling HMD VR Sickness: Pilot Study

4.1 Summary

This was a study on using dynamic FOV (DFOV) constriction to reduce the effects of VR sickness and maintain a high sense of presence while moving in a virtual world using a high-quality head-mounted display and a controller. HMDs allow participants to move their head freely, the representation of their head movements on-screen is adequately one-to-one (under 20ms motion-to-photon latency). However, when a person is asked to move a first-person avatar round, it can induce VR sickness. Prior research reduced FOV to block periphery in order to reduce VR sickness. A majority of the time, however, this was done at the expense of a lower sense of presence. DFOV constriction was introduced as a way of reducing optical flow in order to mitigate VR sickness while allowing the user to maintain a higher sense of presence. Four different settings were tested where there were two speeds of constriction rate (fast and slow) and two settings for maximum FOV constriction (constrict to 70 degrees or 30 degrees FOV). The aim of the study was to observe whether one or more of the vignetting conditions (FOV constriction settings) reduced reported VR sickness and whether it also (adversely) reduced reports of presence as well. DFOV, in this case, refers to the convergence of field of view. While the results showed that presence remained high across all conditions, there were no significant effects on levels of VR sickness. There were mixed reports regarding the functionality of DFOV constriction, where some found it was conducive to a more

comfortable experience, though it was distracting.

4.2 Introduction

VR applications which involve a lot of locomotion in the VEs while being physically static (i.e. sat down) have inherent problems which include the induction of VR sickness [12, 39, 29]. While the user is sitting down and controlling his/her avatar with a controller, there is a sensory mismatch between the first-person avatar's movement and the user's own (lack of) body movement [9, 10, 11]. This is one of the key elements of the interactive experience which designers must confront. While there were solutions for accurately simulating locomotion and body movement in the virtual world, such as full body motion capture and omnidirectional treadmills [57], the aim of this work was to investigate design approaches that work for static workstation set-ups. Therefore it will need to identify and mitigate the factors which contribute to VR sickness by adjusting GUI and camera design.

The design goal of this research was to identify key factors which supported a strong sense of presence without inducing VR sickness. This would allow the user to become familiar with procedures and participate in more active VR applications without the distracting discomfort caused by using these types of immersive HMDs. While some of these factors could be mitigated by upgraded hardware, e.g. screen resolution, better head and positional tracking, the focus of this study is on innovations with virtual camera-based solutions.

4.2.1 Aim

The consumer HMDS being targeted by this research occlude peripheral vision (i.e. fully immersive HMD which blocks the view of surrounding real world) while also using a large field-of-view to display virtual images to each eye. These factors are conducive to VR sickness [13]. The aim was to develop a software-based method for mitigating cybersickness during a wide range of movements without compromising the user's sense of presence.

Removing the occlusion of peripheral vision was not possible with the hardware which was being used. While increased exposure and predisposition to countering the effects due to prior experience and training would help to mitigate these effects [56], significant discomfort could still be caused by more erratic and unpredictable movement [31]. Therefore, the focus of the method was on adjusting the camera display FOV in-

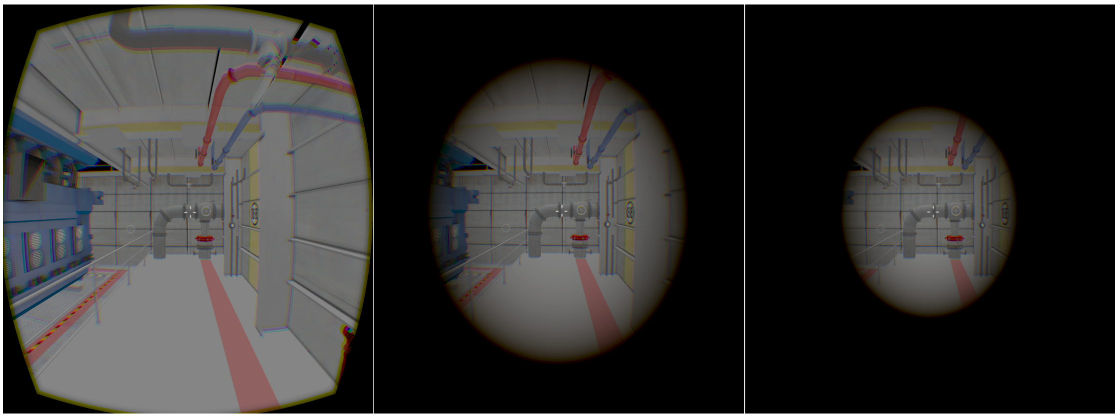


Figure 4-1: Figure showing the different vignetting conditions. From left-to-right: No DFOV Constriction (Control), Wide FOV and Narrow FOV. These effects are applied on top of the barrel distortions applied for the Oculus Rift camera view FOV

game during more intense and busy situations such as transitional animations. The FOV was altered using vignetting effects rather changing the camera properties. This study focused on a possible number of parameters as potential design solutions for minimising VR sickness during transitional animations and rapid or complex character/camera movements.

During transitional animations or rapid movements, the FOV could be adjusted to replicate a similar 'letter-boxing' effect as those which occur in video-game cut-scenes. This would act as a way of reducing optical flow during rapid movements, specifically rotations, of the camera. Finding a method and setting to do this is the goal of this study.

4.3 DFOV Constriction Implementation

The experiment was implemented using the Unity game engine. This shipped with a camera effect script which allowed the developer to add a vignetting and chromatic aberration effect. By tweening the value of vignetting (between 0 and 1) during runtime, the desired effect was achieved. The vignetting effect was used to mask the edges of the camera view by adding a blackened border around the whole view, thus artificially reducing the field of view. This was activated when the camera was rotated beyond a minimum speed set by the experimenter. It also activated when the user triggered a transitional animation. The maximum amount of FOV reduction depended on the experimental condition. Using two extremes, the effect would either be somewhat visible in the periphery or would cover enough of the screen to still allow for a passable field of view. Another variable was the rate of FOV reduction, which determined how much the border effect increased over time while the camera was rotated at a certain speed. The controller was used for locomotion in the virtual world as it is the most typically used modality in modern first-person game and applications, bar keyboard and mouse. It allowed for a more adaptive and controlled movement as the analogue controller allows users to vary their speed of movement and rotation. However, it was this action which was most associated with VR sickness [5].

4.4 Method

The goal of this study was to compare alternative forms of DFOV constriction with a baseline HMD condition, to determine their effects on reported VR sickness and ratings of VR presence. The design used 2 (control vs. intervention) (repeated measures) by 2 (speed of constriction) by 2(field of view). The control condition contained no DFOV solution at all. Each participant was asked to do one control and one of four DFOV conditions.

4.4.1 Apparatus

The introduction of the Oculus Rift Development Kit 2 (DK2) helped to mitigate some of the barriers to immersion which were present with the Oculus Rift Development Kit 1 (DK1). Most notably, the screen resolution and graphical fidelity has improved (DK1 had 640 x 800px per eye and DK2 had 960 x 1080px per eye [4]), with the required refresh rate being increased from 60 to 75fps. The screen, however, though good enough to convey a sense of depth perception, was of relatively low resolution, where there would be a smudging effect when the user moved their head [4]. Oculus implemented solutions to reduce this artificial motion blur, significantly reducing the rate of reported instances of VR sickness during internal demonstrations. This design has now become representative of other HMDs currently under development. The Oculus Rift Development Kit 2 specifications: (5.7" 1920x1080 75 Hz OLED Display, (960x1080 per eye), horizontal FOV 100 degrees) was used, using a beta version of Oculus SDK and runtime environment. The laptop used with GTX 675M Graphics, 16Gb DDR3 RAM, Intel Core i7-3510QM CPU @ 2.30GHz. Test VR application was built with Unity 5.1.2p3. A standard wired Xbox 360 Controller for user input was used.

4.4.2 Participants

Participants comprised of employees within the sponsor company, with experience in software development, naval engineering, naval architecture, human factors and training. In total, 37 participants were tested, 3 of which withdrew during the trials due to experiencing discomfort and VR sickness. This sample was a result of opportunistic recruitment within the partner company. Due to time constraints more could not be recruited. Roughly half of the participants were male, ages ranging from 20 to 57.

4.4.3 Measures

After each trial, the participant was issued with the Simulator Sickness Questionnaire (SSQ) [37]. The SSQ has been used had many prior studies, where it asks questions relating to nausea and oculomotor ability. An edited version of the Presence Questionnaire [20] was used, where questions relating to auditory and haptic factors were omitted. The trials were recorded and transcribed for analysis in the same fashion as the previous study. In addition, prior to the session, each participant was issued with an 'Experience Questionnaire', which indicated the participant's proficiency with a game controller, virtual training and Oculus Rift, and whether they had a history of motion sickness.

4.4.4 Design

Using a mixed model approach, each participant performed the same task twice. In one task the DFOV constriction was not used (control condition (CC)). In the other, one of four vignetting conditions were used. These conditions were based on two independent factors; field of view (FOV) and speed of constriction (SOC), or FOV reduction rate.

The FOV factor comprised of two variants; wide (30% of screen area covered or 70 degrees FOV) and narrow (60% of screen area covered or 40 degrees FOV) (see Figure 4-1). SOC factor comprised of two factors; slow (gradual and noticeable speed) and fast (almost blinking speed). The design was counterbalanced for the order in which participants experienced the intervention vs control (a within-subjects factor). Half of the participants performed the control condition first, whereas the other half performed the DFOV condition first in order to control for practice effect. They were randomly divided equally into one of the four conditions, resulting in 8 groups of conditions altogether.

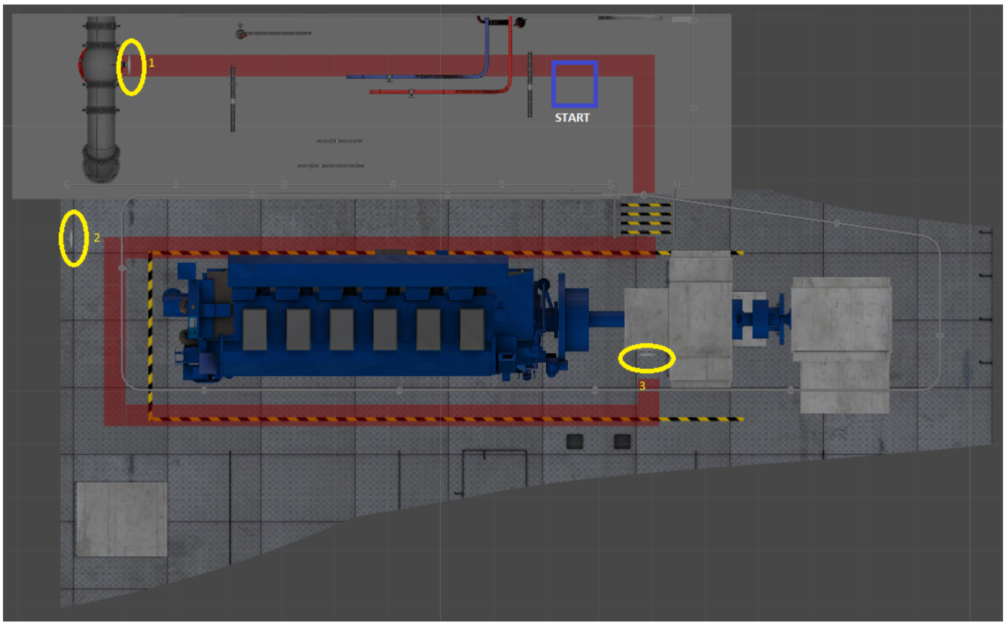


Figure 4-2: Map view showing task route. The valves are circled in order in which they should be turned. The participant is asked to walk back to the start point. The route is designed to encourage the user to turn the avatar a lot in order to fully test the vignetting effect

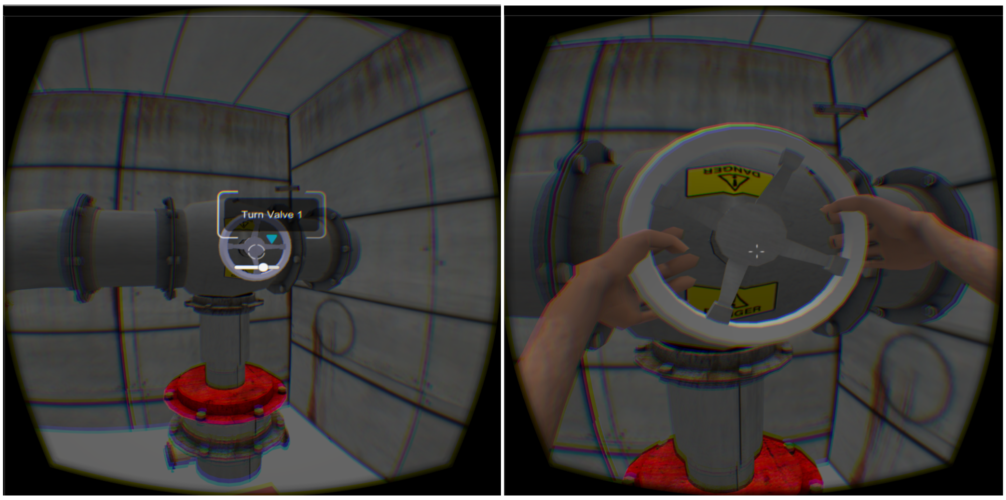


Figure 4-3: Left image showing activation of valve-turning animation using a look-based interaction. Right image is a screenshot mid-animation

4.4.5 Procedure

The participants began the session with a briefing on the task they were asked to do. They were told that they must navigate around a virtual world using the HMD and the controller. Their consent was requested prior to the start of the session. The participants were not informed that the topic of the study was VR sickness until after the session is completed. Instead, they were simply told they were trialling one of the VR demonstrations the author had been developing at the time. Once they were seated with the HMD on, they were asked to become familiar with the setting and asked for their permission to continue. They were then asked to familiarise themselves with the controller. Once the experimenter was satisfied that they were familiar with the controls and were relatively acclimated to the VR environment, the trial was started.

The task itself was set in a mock engine room of a naval vessel. They were asked to follow a red line on the ground. On the route were 3 valves, which they were asked to operate using a look-based interaction (i.e. focussing the reticle over a particular area for a specified amount of time). When this interaction was activated, the avatar moved towards the valve, after which an animation of hands reaching for the valves began. (see figure 4-3). When they reached the 3rd valve, the participant was asked to turn around and follow the route back to where they started. The route itself was designed to encourage the user to rotate the avatar using the controller more than 100 degrees (see figure 4-2). After each trial, the participant was asked to fill in a presence questionnaire and then a simulator sickness questionnaire. When the first trial was completed, they are asked the following two questions:

"What did you think of the task?"

and

"How easy was it to control?"

After the second task they are asked the same two questions plus an additional:

"Did you notice anything different?"

Once the session was complete, the participant was then debriefed on the true nature of the study.

4.5 Hypotheses

It was expected that DFOV constriction would be associated with reduced VR sickness ratings compared to the control condition [13, 1, 10]. Ratings of presence were not expected to differ from the control condition. However if our design rationale was correct, potential differences between the DFOV conditions that contrast wide and narrow FOV would have been observed. In terms of presence the effects of DFOV constriction are not significantly inferior.

H1: Ratings of presence between control and DFOV conditions will not differ. **H2**: Speed of constriction will influence ratings of presence. **H3**: Degree of FOV reduction will influence ratings of presence. **H4**: Speed of constriction and FOV reduction will interact on ratings of presence **H5**: Ratings of VR sickness between control and DFOV conditions will differ. **H6**: Speed of constriction will influence ratings of VR sickness. **H7**: Degree of FOV reduction will influence ratings of VR sickness. **H8**: Speed of constriction and FOV reduction will interact on ratings of VR sickness

4.6 Results

This section outlines the results obtained from the questionnaires, followed by a subsection giving an overview of themes which emerged from qualitative feedback via Thematic Analysis [26, 27].

4.6.1 Questionnaire Data

All participants were assigned randomly to perform the control or DFOV task first (half of the sample size in each condition), to counterbalance against possible order effects (e.g. practice, fatigue or cumulative sickness).

An ANOVA was used to analyse the total presence and SSQ scores. The maximum possible presence score was 175 (25 items, each rated from 1 to 7), and the maximum possible sickness score was 48 (16 items, each rated from 0 to 3). Descriptive statistics of the Experience questionnaire are provided in Table 4.1. We first report the results for our adapted version of the Witmer and Singer Presence Questionnaire [20].

Presence Analysis

Our expectations for Presence ratings were that the novel vignetting design would preserve the strong sense of presence that immersive HMDs can offer compared to control.

The ANOVA shows no evidence of a significant difference in presence ratings, either as a general contrast between DFOV and control (F=1.651 (24,1); p=.211; w=.235). The mean presence scores both for control (136.48 SD=13.78) and for DFOV constriction (134.55, SD=14.93) were both high.

Experience Questionnaire

	N	Minimum	Maximum	Mean	Std. Deviation
Experience With Controllers	33	1	3	2.27	.674
Experience With Virtual Training	33	1	2	1.27	.452
Experience with Oculus Rift	33	1	2	1.55	.506
Motion Sickness History	33	1	2	1.42	.502
Motion Sickness from HMD	33	1	4	1.76	.867
Valid N (listwise)	33				

Table 4.1: Descriptives for Experience Questionnaire. Questions 1 to 4 were rated on a three-point scale, Question 5 contained five scale points

Turning our consideration to the potential for a specific advantage to one of the vignetting parameters, we similarly find no significant difference in ratings.

For speed, fast did not differ from slow (F=.3, (24,1); p=.865; w=.053). The mean rating for fast (134.53, SD=12.304) and slow (134.56, SD=17.716) were both high.

For FOV, wide did not differ from narrow (F=.575, (24,1); p=.456; w=.113). The mean rating for wide (138.50, SD=18.388) and narrow (130.82, SD=9.914) were both high.

There was no special advantage or disadvantage for combinations of the speed and FOV factors, in terms of interaction effect on presence ratings (F=1.159, (24,1); p=.292; w=.179).

VR Sickness Analysis

Our expectations for SS ratings were that the novel DFOV constriction design would reduce the level of VR sickness compared with the control condition

The ANOVA shows no evidence of a significant difference in VR sickness, either as a general contrast between DFOV and control (F=1.302 (24,1); p=.265; w=.195). The mean presence scores both for control (2.30 SD=2.555) and for DFOV constriction (2.27, SD=2.625) were both low.

Turning our consideration to the potential for a specific advantage to one of the vignetting parameters, we similarly find no significant difference in ratings.

For speed, fast did not differ from slow (F=.546, (24,1); p=.467; w=.109). The mean rating for fast (2.76, SD=3.011) and slow (1.75, SD=2.113) were both low.

Mean Scores for SSQ and Presence

	Speed	FOV	Mean	Std. Deviation	N
SSQ Control(48)	fast	narrow	3.78	3.833	9
		wide	1.50	1.414	8
		Total	2.71	3.098	17
	slow	narrow	2.00	1.512	8
		wide	1.75	2.188	8
		Total	1.87	1.821	16
	Total	narrow	2.94	3.030	17
		wide	1.62	1.784	16
		Total	2.30	2.555	33
SSQ Vignetting(48)	fast	narrow	3.00	2.646	9
		wide	2.50	3.546	8
		Total	2.76	3.011	17
	slow	narrow	1.75	2.252	8
		wide	1.75	2.121	8
		Total	1.75	2.113	16
	Total	narrow	2.41	2.476	17
		wide	2.13	2.849	16
		Total	2.27	2.625	33
Presence Control (175)	fast	narrow	136.11	10.493	9
		wide	136.63	13.169	8
		Total	136.35	11.445	17
	slow	narrow	131.63	15.250	8
		wide	141.62	16.698	8
		Total	136.63	16.289	16
	Total	narrow	134.00	12.733	17
		wide	139.13	14.755	16
		Total	136.48	13.780	33
Presence Vignetting (175)	fast	narrow	132.44	7.265	9
		wide	136.88	16.548	8
		Total	134.53	12.304	17
	slow	narrow	129.00	12.536	8
		wide	140.13	21.088	8
		Total	134.56	17.716	16
	Total	narrow	130.82	9.914	17
		wide	138.50	18.388	16
		Total	134.55	14.927	33

Table 4.2: Mean scores of participants in Presence and SSQ in all conditions

For FOV, wide did not differ from narrow (F=.850, (24,1); p=.366; w=.144). The mean rating for wide (2.13, SD=2.849) and narrow (2.41, SD=2.476) were both low.

There was no special advantage or disadvantage for combinations of the speed and FOV factors, in terms of interaction effect on VR sickness (F=1.072, (24,1); p=.311; w=.169).

4.6.2 Qualitative Reflections of Participants

We wished to deepen the understanding of user experience in immersive interactive virtual worlds to further drive our design work. We were concerned with qualities of presence that may not be captured by the PQ or SSQ. This section is based on transcriptions of participants' feedback and answers to questions. Two researchers reviewed the transcribed comments as a set to find a simple scheme for categorising them. One participants' qualitative data is not present due to technical issues with the recorded video. The majority of the extracts are in response to the questions outlined in the 'Design' in the 'Methods' section. Some of the extracts are observations and comments made during the actual task or after the study was completed.

The stages of Thematic Analysis are outlined in Chapter 2. During the first pass of the transcripts, salient quotes were extracted and assigned labels. After this, the first pass was performed where the following themes emerged:

- Better than the first trial
- Noticed Constriction
- Constriction caused discomfort
- Constriction was distracting
- Constriction was helpful
- General discomfort
- Rotation caused discomfort
- Transitional animations caused discomfort
- Movement caused discomfort
- Controller Issues
- Did not move their head
- Head-body disconnect
- Suggested constriction method

The author found it was appropriate to assign multiple labels to quote and vice-versa due to the nature of the comments. For example, some participants observed that they noticed the constriction effect and that while they found it helped them to feel more comfortable, it was distracting. Before delving into which comments pertained to the benefits or disadvantages of each constriction method, four major themes were identified. The author chose to use these as a template for categorising some of the quotes before delving into another level of thematic analysis due to the overlapping nature of a lot of the quotes. Below is a detailed observation of the quotes during this pass:

VR Sickness and Disorientation regarding physical discomfort, where users made comments relating to sickness and or disorientation either caused by FOV constriction or by the VR experience in general.

- Better than first trial
- Constriction caused discomfort
- Constriction was helpful
- General discomfort
- Rotation caused discomfort
- Transitional animations caused discomfort

Visual/Perceptual Elements prominently comments and thoughts on the DFOV constriction settings, where participants noticed its presence or remarked on it's benefits or disadvantages.

- Noticed Constriction
- Constriction was distracting
- Suggested constriction method

Controller: Comments on the use of Xbox controller and the ability to walk around in the virtual environment. This includes remarks about the difficulty in reconciling between controller and head motions.

- Controller Issues
- Head-body disconnect

Motion General comments on motion in the VE.

- Movement caused discomfort
- Did not move their head

It was also noted whether the participants noticed the difference between the first and second trial (i.e. DFOV or control). As highlighted in the result tables for figures 4-4, 4-5, 4-6 and 4-7, there were many quotes pertaining to discomfort experienced as the result of a number of factors. The second theme was based on quotes where the participant was aware of the DFOV constriction effect. This theme exists as an aversion to DFOV constriction did not necessarily correlate with discomfort or sickness.

Participant	SS and Disorientation		Visual/Perceptual elements		Controller		Motion		Notice Difference?
	Subtheme	Quote	Subtheme	Quote	Subtheme	Quote	Subtheme	Quote	
1 C SW	Better than first trial	[SW] Yeah I thought it was a lot smoother	Noticed Constriction	[SW] Is that supposed to happen? [referring to vig]					Yes
2 C SW	Rotation caused discomfort	[C] The rotation seemed to be the most confusing part for your sense of balance anyway.	Noticed Constriction	[SW] Yes, you're restricting the field of view I suppose when turning left and right					Yes
3 C SW	Transitional animations caused discomfort	[C] The only bit that felt a bit weird was when you get a bit close to the valves it locks on and drags you forwards. Because you weren't in control that was disorientating.	Noticed Constriction	[SW] Nice bit of tunnel vision there	Controller issues	[SW] So quite used to staring ahead at the television at home and doing all of the controlling on the controller, which doesn't move much, rather than having to look around me while I'm doing it.			Yes
	Transitional animations caused discomfort	[a] I felt the most motion sickness during transitional animation	Noticed Constriction	[SW] Apart from the tunnel vision? When you're moving from side to side you're getting tunnel vision. I'm assuming that's there to encourage you to look around more.					
4 C SW	Constriction caused discomfort	[SW] Yeah while it was turning, it felt like a sort of black halo was causing some sort of tunnel vision. That was a bit weird and disorientating doing it.	Constriction was distracting	[SW] Yeah while it was turning, it felt like a sort of black halo was causing some sort of tunnel vision. That was a bit weird and disorientating doing it.			Movement caused discomfort	[C] You can definitely feel the sensation of moving more a little bit in this	Yes
5 C SN			Constriction was distracting	[SN] Different from last time because of the black, but it didn't feel noticeably easier or harder.					Yes
6 C SN	Rotation caused discomfort	[C] Ooh that's a bit weird when (I) travel in there [when turning valve] That motions quite (sickening) [when rotating with controller]	Constriction was distracting	[SN] I think that peripheral vision thing. It does help but it is quite annoying.	Head-body disconnect	[C] Well because you got that (controller) motion and your head motion, it feels a bit hard to keep on top of which way you are looking.	Movement caused discomfort	[SN] Yeah I didn't get the stomach awareness apart form when I went down here [down the stairs] and when it does the little animation bits [turning of the valves].	Yes
	Better than first trial	[SN] That's definitely not so bad, that motion there [referring to turning second valve].							
	Constriction was helpful	[SN] I think that peripheral vision thing. It does help but it is quite annoying.	Constriction was distracting	[SN] I think that peripheral vision thing. It does help but it is quite annoying.					
	Transitional animations caused discomfort	[SN] Yeah I didn't get the stomach awareness apart form when I went down here [down the stairs] and when it does the little animation bits [turning of the valves].							
7 C SN	Rotation caused discomfort	[C] The turning with the button (analogue stick) and the turning of the head is a bit (disorientating).	Constriction was distracting	[SN] As far as walking around, I willing to admit that it [vignetting] does help with motion sickness, because I'm now walking around, moving my head and walking and not feeling weird. So yeah I think it helps the motion sickness. Which is great. Obviously there's kind of a sacrifice in awareness. But I guess motions sickness is bigger issue than total vision.	Head-body disconnect	[C] The turning with the button (analogue stick) and the turning of the head is a bit (disorientating).	Did not move head	[SN] I adapted to the whole confusion with moving my head and moving the controller…by just not moving my head, and that kind of helped.	Yes
	Constriction was helpful	[SN] As far as walking around, I willing to admit that it [constriction] does help with motion sickness, because I'm now walking around, moving my head and walking and not feeling weird. So yeah I think it helps the motion sickness. Which is great. Obviously there's kind of a sacrifice in awareness. But I guess motions sickness is bigger issue than total vision.					Did not move head	[SN] Was a lot easier because I didn't move my head much (Not moving head)	

Figure 4-4: Thematic Analysis part 1 showing results from participants who performed the control task followed by an experimental task

Participant	SS and Disorientation		Visual/Perceptual elements		Controller		Motion		Notice Difference?
	Subtheme	Quote	Subtheme	Quote	Subtheme	Quote	Subtheme	Quote	
8 C SN			Constriction was distracting	[SN] More difficult than last time, just getting used to the tunnelling. More I turn it blacks out.					Yes
9 C FW	Rotation caused discomfort	[C] Wow yeah I can see why people get motion sickness [turning to go to the last valve]		[FW] I don't like that…that looking thing [turning just before the stairs, referring to vignetting] I actually think it feels better when you're moving around with that vision thing[FW] I don't like that…that looking thing [turning just before the stairs, referring to vignetting] I actually think it feels better when you're moving around with that vision thing					Yes
	Constriction was helpful	[FW] I don't like that…that looking thing [turning just before the stairs, referring to vignetting] I actually think it feels better when you're moving around with that vision thing	Constriction was distracting	[FW] I don't like that…that looking thing [turning just before the stairs, referring to vignetting] I actually think it feels better when you're moving around with that vision thing					
	Constriction was helpful	[FW] Everytime I moved the joystick to turn, I get a slightly narrowing of the vision which I think reduces that full head feeling	Constriction was distracting	[FW] Everytime I moved the joystick to turn, I get a slightly narrowing of the vision which I think reduces that full head feeling					
10 C FW			Constriction was distracting	[FW] Don't like this new thing when you turn [vignetting]			Movement caused discomfort	[C] It was weird when it went to grab the valve and turn it, that felt a bit weird.	Yes
			Constriction was distracting	[FW] Yeah that was alright, I didn't like that new black thing coming in. It sort of restricted the vision a bit, and it just felt a bit weird. Obviously that wouldn't happen when you're moving your head					
11 C FW	Constriction was helpful	[FW] That's weird isn't it, when you put dark it's fine. Yeah that doesn't effect me at all. It was really jolty before. So when it goes black round there, it's fine.	Noticed Constriction	[FW] That's weird isn't it, when you put dark it's fine. Yeah that doesn't effect me at all. It was really jolty before. So when it goes black round there, it's fine.	Head-body disconnect	[a] Would have preferred for body to move where she was looking	Movement caused discomfort	[a] Would have preferred for body to move where she was looking	Yes
	Constriction was helpful	[FW] Yeah the second one was a lot better. I didn't feel any sickness.	Constriction was distracting	[a] liked the vignetting but was a bit distracting.					
12 C FW	Constriction caused discomfort	[FW] It's a bit disorientating, it makes feel like you're blinking but you're not	Noticed Constriction	[FW] I noticed the black kicking in or something.					Yes
14 C FN			Noticed Constriction	[FN] I presume I'm supposed be getting that weird tunnel vision thing.					Yes
			Noticed Constriction	[FN] Yeah that black edging… vignette.					
			Suggested Constriction Method	[a] might be better to blur the periphery rather than use black {Suggested Constriction Method}					
15 C FN	General discomfort	[C] Made me feel a little queezy. Though you sort of get used to it.	Noticed Constriction	[FN] Very similar really, just the blocking out on the sides as you turned it.					Yes
16 C FN			Noticed Constriction	[FN] Interesting on this one how your vision narrows down as you're turning, almost like a telescope of some form. The peripheral vision closes down to blackness. Its when you're turning. Obviously the quicker you turn					Yes
25 C FN	Rotation caused discomfort	[FN] Had the sort of vision getting small when using the controller. Kind of probably helped a bit in terms of feeling better, although I did one movement and made me feel ill… that was looking and turning at the same time.	Noticed Constriction	[FN] Had the sort of vision getting small when using the controller. Kind of probably helped a bit in terms of feeling better, although I did one movement and made me feel ill… that was looking and turning at the same time.			Movement caused discomfort	[FN] Had the sort of vision getting small when using the controller. Kind of probably helped a bit in terms of feeling better, although I did one movement and made me feel ill… that was looking and turning at the same time.	Yes

Figure 4-5: Thematic Analysis part 2 showing results from participants who performed the control task followed by an experimental task

Participant	SS and Disorientation Subtheme	SS and Disorientation Quote	Visual/Perceptual elements Subtheme	Visual/Perceptual elements Quote	Controller Subtheme	Controller Quote	Motion Subtheme	Motion Quote	Notice Difference?
17 SW C	Better than first trial	[C] Yeah it didn't go dark round the edges when I looked left and right and stuff. Weirdly enough I felt less ill this time round, but it might be me getting used to the Oculus.	Noticed Constriction	[C] Yeah it didn't go dark round the edges when I looked left and right and stuff. Weirdly enough I felt less ill this time round, but it might be me getting used to the Oculus.					Yes
18 SW C	Constriction was helpful	[C] But it made me feel a little bit nauseous that time.			Controller issues	[SW] I think I learnt it fairly quickly, I think I could do it faster, but getting the coordination of right and left (thumb stick) is something I need to fix in my mind I think	Movement caused discomfort	[SW] Easy as long as I went slowly.	No
19 SW C									No
20 SW C									No
21 SN C	Constriction caused discomfort	[C] Found the turning less strange without the view closing in. I think I felt dizzier though. Thought it felt more natural than the sort of black border coming in.	Constriction was distracting	[SN] Find it strange when your vision closes in when turning, which I find disconcerting. And when you first turn the valve it moves you forward. That was disconcerting as well. Just find that really weird, really strange.			Movement caused discomfort	[SN] Find it strange when your vision closes in when turning, which I find disconcerting. And when you first turn the valve it moves you forward. That was disconcerting as well. Just find that really weird, really strange.	Yes
			Constriction was distracting	[C] Found the turning less strange without the view closing in. I think I felt dizzier though. Thought it felt more natural than the sort of black border coming in.					
			Constriction was distracting	[C] Found it easier, cus the closing in was distracting last time.					
22 SN C									No
23 SN C			Noticed Constriction	[SN] This field keeps narrowing. Is that normal? Every time I move the looking stick it feels narrow.					No
24 SN C					Controller issues	[SN] [had some trouble with the controls]			No
					Controller issues	[SN] Takes a bit of getting used to it with combining movements. (Controller Issues)			
26 FW C			Noticed Constriction	[FW] Is there a reason why it goes slightly darker when you're turning the body?					No
27 FW C									No
28 FW C					Controller issues	[FW] Fairly simple, just a bit weird to navigate.			No
29 FW C							Movement caused discomfort	[FW] I can see why people would get motion sick because when you start moving, you do feel uneasy, but its not bothering me, but I can see why the motion in enclosed space can cause discomfort.	No
30 FN C	Constriction caused discomfort	[FN] Yeah it's fine, just the focus with the tunnel vision is a bit disorientating.	Noticed Constriction	[FN] Sorry, why does it zoom in or go into tunnel vision?					Yes
	Constriction caused discomfort	[C] Yeah it's a lot less disorientating without the tunnel vision	Constriction was distracting	[FN] Yeah it's fine, just the focus with the tunnel vision is a bit disorientating.					
	Constriction caused discomfort	[C] Yeah it was much better without the tunnel vision	Constriction was distracting	[C] Yeah it's a lot less disorientating without the tunnel vision					
			Constriction was distracting	[C] Yeah it was much better without the tunnel vision					

Figure 4-6: Thematic Analysis part 3 showing results from participants who performed an experimental task followed by the control task

Participant	SS and Disorientation		Visual/Perceptual elements		Controller		Motion		Notice Difference?
	Subtheme	Quote	Subtheme	Quote	Subtheme	Quote	Subtheme	Quote	
31 FN C	Constriction caused discomfort	[FN] In terms of the controls, slightly tricky. I didn't feel any sense of disorientation really. Obviously we have the phenomenon of the closing down field of view as I'm turning around. It's when I look around corners and go around corners, it's closing down that field of view, and it makes it difficult.	Constriction was distracting	[FN] In terms of the controls, slightly tricky. I didn't feel any sense of disorientation really. Obviously we have the phenomenon of the closing down field of view as I'm turning around. It's when I look around corners and go around corners, it's closing down that field of view, and it makes it difficult.	Head-body disconnect	[FN] Just a little bit difficult to coordinate the forward motion with where I'm looking. I'm finding that if I'm just going to go direction-wise, I'd like to be able to go where I'm looking. I think that narrowing FOV is an odd sensation and a bit restrictive really because I'm expecting to get some more peripheral vision as I turn a corner, and I'm losing that.			Yes
	Constriction caused discomfort	[C] Good, slightly better than I think…without the narrowing of field of view that does help me going around corners. I feel fine, quite comfortable in the environment							
	Constriction caused discomfort	[FN] Just a little bit difficult to coordinate the forward motion with where I'm looking. I'm finding that if I'm just going to go direction-wise, I'd like to be able to go where I'm looking. I think that narrowing FOV is an odd sensation and a bit restrictive really because I'm expecting to get some more peripheral vision as I turn a corner, and I'm losing that.							
33 FN C	Better than first trial	[C] It should have been easier on this one because when you're turning, it didn't take out the peripheral vision, and I feel that should have been that much easier	Noticed Constriction	[FN] When you're rotating it seems to go dark round the edges…round the peripheral vision					Yes
			Constriction was distracting	[FN] The only thing was when you were turning, the peripheral vision started going a little bit. That made me turn at the last minute. Going through the engine you could usually cut the corner. But because you don't get the peripheral vision I sort of went right to the edge of the red marking right before turning.					
			Constriction was distracting	[C] It should have been easier on this one because when you're turning, it didn't take out the peripheral vision, and I feel that should have been that much easier					
34 FN C	Constriction was helpful	[C] Was that intentional before when I was turning left and right I would get like a black gui circle coming into the centre, whereas in this one it's (not there)? But certainly seems a little more disorientating just walking around in this one. A little bit harsher on the eyes, when you turn it feels a little bit strange. It's kind of horrible.	Constriction was distracting	[C] Was that intentional before when I was turning left and right I would get like a black gui circle coming into the centre, whereas in this one it's (not there)? But certainly seems a little more disorientating just walking around in this one. A little bit harsher on the eyes, when you turn it feels a little bit strange. It's kind of horrible.					Yes
	Constriction was helpful	[C] think it felt a lot easier just not having the outline around when turning left and right. It seemed to feel a lot less free moving around. A little bit more restrictive [referring to previous trial]. But I feel a lot dizzier (this time round). I'm starting to get a little bit of a head ache from it.	Constriction was distracting	[C] think it felt a lot easier just not having the outline around when turning left and right. It seemed to feel a lot less free moving around. A little bit more restrictive [referring to previous trial]. But I feel a lot dizzier (this time round). I'm starting to get a little bit of a head ache from it.					

Figure 4-7: Thematic Analysis part 4 showing results from participants who performed an experimental task followed by the control task

Nine participants indicated that they found the DFOV constriction helped to ease the feelings of sickness, although they found it to be distracting. Examples of these comments include

"[P6:SN] I think that peripheral vision thing. It does help but it is quite annoying."

Participants seemed more attuned to the DFOV constriction when moving around in the VE.

"[P7:SN] As far as walking around, I willing to admit that it [DFOV constriction] does help with motion sickness, because I'm now walking around, moving my head and walking and not feeling weird. So yeah I think it helps the motion sickness. Which is great. Obviously, there's kind of a sacrifice in awareness. But I guess motions sickness is a bigger issue than total vision."

In a different condition:

"[P9:FW] I don't like that... that looking thing [turning just before the stairs, referring to vignetting] I actually think it feels better when you're moving around with that vision thing"

Participants rarely used the term 'sickness', despite the potential priming influence of the SSQ. Participants regularly referred to the term 'disorientation'. In seven cases the DFOV constriction was aided in causing disorientation, some feelings of sickness and felt unnatural. Comments include examples such as

"[P10:FW] Don't like this new thing when you turn [vignetting]. Yeah, that was alright, I didn't like that new black thing coming in. It sort of restricted the vision a bit, and it just felt a bit weird. Obviously, that wouldn't happen when you're moving your head"

"[P31:FN] In terms of the controls, slightly tricky. I didn't feel any sense of disorientation really. Obviously, we have the phenomenon of the closing down field-of-view as I'm turning around. It's when I look around corners and go around corners, it's closing down that field of view, and it makes it difficult... without the narrowing of field-of-view that does help me going around corners. I feel fine, quite comfortable in the environment".

One of these participants [P3:SW] went on to speculate that the DFOV constriction was

"there to encourage you to look around more",

suggesting it was there to be purposefully restrictive.

Extracts from those participants who did the DFOV conditions first differed slightly. 10 of the 16 participants, when asked if they noticed anything different from the first trial, did not notice anything during the second trial.

Two participants made a suggestion that it may be better to blur the periphery rather than using a solid black vignette as they felt it would be less intrusive. Two of participants suggested that the task simply was not engaging enough for acquiring readings on sickness and presence:

"[P28:FW] I felt that I was not immersed enough to make a decision as to whether one scenario was more immersive than the other. I needed sound to really increase my immersion, and it to be faster as I was starting to lose concentration The task was simple enough so that you could explain it beforehand."

"[P33:FN] I was sort of expecting something to happen. Maybe some water to come or something for me to react to. I was surprised that nothing happened. You probably noticed I was looking around quite a bit"

While there was no particular uniformity of concern evident in comments specific to the type of DFOV constriction, it was observed that there was a general mix in reaction to vignetting.

4.7 Discussion

The fact that there were no significant differences in presence ratings across all conditions is a positive. This was an indication that regardless of some of the hindrances created by DFOV constriction, a high sense of presence was still maintained. The lack of significant differences in reported VR sickness across all conditions did not conform to the expectations of this study. What was surprising was that raw SSQ scores were consistently low, suggesting a possible floor effect. The tasks and motion path were intended to contain the risk of VR sickness, after pilot studies which involved head and body movement in the virtual world. As stated by some participants, the level of engagement was low in general. The author concluded from observation of the trials the task itself was not engaging enough, i.e. boring to perform. It was also not visually varied enough to induce much VR sickness in the first place.

As a counter to this point, the possibility of this task inducing VR sickness was present, as three participants had to withdraw mid-session, and other participants did report some form of discomfort. It was noted, where participants commented on side-effects of DFOV constriction they referred to (a) tunnel-vision which reduced their awareness of the space, making walking awkward and (b) disorientation. They rarely mentioned sickness, nausea or other forms of this kind. Disorientation could have meant a number of things, from a sense of losing spatial reference in the environment through to virtual confusion. It suggests at least that DFOV constriction has avoided strong physiological aversion. It perhaps raised another lesser but important challenge for HMD interaction design in virtual worlds to avoid disorientation as well as maintaining presence.

The qualitative analysis yielded some salient points, where some of the participants were giving feedback which corroborates previous research. As with the findings reported in [51], participants were reporting that while static FOV reduction conditions did help with reducing the effects of VR sickness, DFOV constriction was proving to be a distraction. In other cases, users were reporting that the constriction was a hindrance to navigation, and was in fact causing some disorientation.

From these results, it is difficult to tell how much is influenced by factors such as fatigue and practice effect. The question of exposure time should also be factored in. Each trial lasted roughly between 1.5 to 2 minutes. Within these trials, participants were asked to 'walk' around a virtual environment and interact with 3 virtual valves, each of which initiated the same animation. This design was chosen for ethical purposes, i.e. keeping exposure time to a safe amount in consideration of those who had not used an immersive HMD before. As stated previously this may have resulted in an unintended floor effect.

It may also have been prudent to have more control over the recruitment of participants. For example, it may be better to limit the criteria to only allow those with sufficient experience with the control mechanism, i.e. the Xbox controller. There were some participants who had such difficulty with the control mechanism, some of them reported that discomfort was a result of their confusion with which analogue stick to use for which direction. One user even stated that they moved so slowly that it was possible that they did not notice the vignetting effect ([P7:SN] and [P24:SN]). The tasks themselves could also be adjusted depending on proficiency with game controllers and susceptibility to motion sickness. This could mean that those with, e.g. high level of controller proficiency and no history of motion sickness could participate in a more 'sick-inducing' task.

Qualitative feedback did not fully corroborate the quantitative analysis. The author speculates that this may partially be due to the order in which the user completed questionnaires. If the SSQ was issued first, directly after the user had removed the HMD, it may have helped to capture a more accurate and immediate representation of the users' sickness level. The SSQ is far simpler to complete and requires far less reading and attention, whereas the altered presence questionnaire required significantly more time and effort to complete. A baseline SSQ test should have also been completed prior to the trial beginning in order to rule out other outside influences on the participant's physiological state. As the user completed the presence questionnaire first, it is possible to assume that the fleeting feelings of VR sickness may have dissipated over the time taken to complete the presence questionnaire. Nevertheless, the issue of disorientation as distinct from sickness remains.

One major barrier for a number of participants was the ability to use the game controller. Some of the adverse effects could have been attributed to much of the cognitive energy being spent on familiarising themselves with the controller. Other attributes could include the lack of calibration control, e.g. the character's speed of movement and rotation. An introduction scene, even without the HMD, could have been used to gauge the participant's preferred movement and rotation speeds. An advantage to withholding this ability, however, is that keeping all configurations the same will reduce other influential factors. Like the trial order, this factor would also need to be balanced, going back to the need to control participant recruitment in order to have an even spread of proficiencies and susceptibilities.

The DFOV constriction function itself could be adjusted. Regardless of the level of FOV, participants would still notice the constriction effect (or not notice that it was absent second time around). In further implementations, FOV should be kept to values closer to the 'wide' setting, as the narrow setting is intrusive. Other aspects to consider are the effect itself. Though the results showed that speed of FOV constriction did not seem to be much of a differentiating factor, it would be interesting to observe its effects in more erratic camera movements. As stated in the results, there was a suggestion that the vignetting effect itself be altered so that the vignetted area is blurred rather than coloured black i.e. a more foviating effect than a blinking effect. The DFOV constriction functions should be tested on more demanding and fast-paced virtual applications, as this is what it was originally designed for. Tasks should involve more transitional animations and a more bombastic and animated scene in order to really test the effects. The VE should incorporate sounds and audio-based hints and other elements to increase baseline immersion.

4.8 Conclusion

This chapter introduced a new method (at the time) for using FOV manipulation to reduce VR sickness. The aim was to develop a dynamic FOV constriction method which would allow the participant to maintain a sense of presence by mitigating the disruptive nature of FOV manipulation. This constriction was based on translational velocity of the first-person avatar the participant operated. Prior work has depended on fixed restrictions on peripheral vision in HMDs, typically eroding the very sense of presence that otherwise characterizes HMD interaction. Therefore this chapter reported an exploration of the design possibilities by experimenting with two parameters: the degree of FOV constriction, and the rate of constriction over time.

This study explored the potential of DFOV constriction in HMD-based VR applications. Our quantitative analysis showed that while a high sense of presence was maintained between conditions with and without DFOV, there were no significant differences across any conditions in levels of VR sickness. However, our qualitative analysis succeeded in delivering a better understanding of reactions to this mechanic; an insight which the quantitative analysis could not give. There was a general sense that the participants referred to their discomfort more as disorientation rather than sickness. Whether this has an overall influence on results is yet to be investigated. In accordance with prior research, restricting FOV was generally perceived as helping to relieve discomfort but, in contrast with prior research, not at the expense of presence. However, DFOV constriction still poses challenges for users as a potential source of annoyance and a distraction. This suggests that DFOV constriction is a productive form of HMD sickness countermeasure but further study is needed on the mechanic.

A future study was moulded by attempting to work with some of the design problems of this study. It was clear that a more visually demanding task and setting was needed in order to elicit some physiological response (without DFOV constriction). Trial time would have to be increased, where the participant would use the VR headset for a considerably longer time than (longer than 2-3 minutes). The task itself would have needed to be more engaging in order to motivate the participant's involvement in the virtual world. Some suggestions include tasks which require a degree of searching or puzzle solving, where the participant is required to move large distances. The setting of the task could also be considered. The task in this study was based in a cramped engine room. A range of settings, from indoor to outdoor could be tested in a similar fashion. While this was the first study to attempt this, a lot of improvement needed to be made in order for it to begin to be effective in combating VR sickness.

Chapter 5

Main Study: Reducing VR Sickness using Dynamic FOV Convergence During Exaggerated Movements

5.1 Introduction

This expanded the Dynamic FOV (DFOV) constriction to test whether it can help to mitigate VR sickness during more erratic and exaggerated camera movements. Participants were placed on a virtual ship where they were asked to navigate the deck. After a period of time, the ship would begin to rock and sway. At certain angles, this caused the virtual avatar to 'stumble'. This involved the software taking control of the avatar's movements and camera, which is currently strongly advised against in VR best-practice guides [2]. Based on previous research (see Chapter 4) and literature it was hypothesised by the author that DFOV constriction could make these animations and action feasible and comfortable in first-person VR applications. Each participant was asked to complete the trial twice per session, with a break in between. In one trial, DFOV constriction was not implemented, whereas in the other trial it was. The participants' task was to follow a set of way-points which appeared one at a time. The trial was terminated at the experimenter's discretion if they felt the participant had completed the task, or if they were unable to continue due to too high levels of discomfort, nausea etc.

5.2 Background and Motivation

The previous study in Chapter 4 highlighted that improvements in the methodology were required in order to yield valid results. One of the biggest criticisms was that the task itself was not engaging enough. In addition, there may not have been enough movement to induce VR sickness, and therefore not provide a solid platform to evaluate the effectiveness of FOV constriction.

A study was presented at 3DUI at the IEEEVR conference (after the study in Chapter 4), which contained a similar research question. Fernandes and Feiner [1] claimed that their method of dynamically reducing FOV, while maintaining presence, significantly reduced the induction of VR sickness. Although this same method was tested by Bolas et. al (2014) [58], the method in Fernandes and Feiner's paper [1] was of a similar implementation to the one the author used.

Fernandes and Feiner asked participants to navigate around a VE following a set of way-points. It required a certain degree of exploration, which in-tandem would require a lot more rotational and translational movements by the participant. While they were moving, the DFOV constriction would occur. The difference in DFOV implementations of the author and Fernandes and Feiner was that they were taking both translational velocity and angular velocity (rotation of virtual body) into account. The DFOV parameters in the author's previous study were only effected by translational velocity.

The aim of the study in this chapter was, therefore, to build on the theories and implementation of DFOV constriction. Although Fernandes and Feiner ([1]), and other FOV constriction studies ([59, 51, 52, 53]) show that VR sickness ([12]) can be reduced while a user is moving around a virtual environment, it does not indicate whether DFOV constriction could be used for a wider range of movement.

The motivation was to explore the possibilities of allowing more exaggerated movements to be simulated in first-person VR applications. Facets which are present in typical first-person applications are not present in most VR applications, in which the user is stationary and controlling movement through the use of a game controller. These facets include head-bobbing, falling, stumbling, somersaults etc. An example is the game "Mirror's Edge", a computer game where the player controls a first-person avatar who is a free-runner. A VR version of this would currently not be possible, as it would require taking control of the camera often, for example, when the character lands a jump and performs a forward roll, or when the character is knocked down by a guard. Relinquishing control of the camera like this, i.e. the camera being moved without input from the user, contributes greatly to VR sickness [2, 59, 51], and therefore is not recommended in current VR applications.

To test whether DFOV constriction could help to mitigate VR sickness during these involuntary movements, a method was designed which would induce enough VR sickness to be measured, but not enough to cause severe symptoms. This was determined during prototyping of the virtual task and mechanics by gaining informal feedback from colleagues. The method chosen to elicit a physiological response (while still being ethically tolerable) was to have the character stumble in response to an environmental stimulus. The details are noted later in this chapter. It required a degree of loss-of-control, where the character would begin to travel in a direction unintended by the user, as well as some minor head-bobbing to further simulate the sensation of stumbling. The author considered adding in other facets such as falling onto the ground and/or rolling. However, in preliminary tests done in the design phase, it was decided this would not be suitable as not only would it introduce too many variables to test at once, it was found to result in immediate termination of trials due to too much discomfort or nausea.

The aim therefore was to observe whether DFOV Constriction significantly mitigated discomfort and VR sickness and subsequently whether it interfered in the participant's sense of presence.

5.3 Experimental Setup

5.3.1 Equipment

An Oculus Rift Development Kit 2 (ORDK2) was used. The ORDK2 has integrated 6-degrees-of-freedom positional and rotational tracking. The application used in the study was built in Unity 5.3.5f1 and run using Oculus Runtime/SDK 1.7. The machine used was an ASUS Republic Of Gaming laptop with GTX 980M Graphics Card, Intel Core i7-4870HQ processor (2.50GHz), 32 GB RAM, running Windows 8.1. An "XBox 360 wired controller for PC" was used by participants to move their first-person avatar around the environment, wearing standard PC headphones.

5.3.2 DFOV Constriction

The dynamic FOV constriction was implemented through a script which utilised the "Vignetting and Chromatic Aberration" (or VCA) script [60] which is included as standard with Unity 5. This is a different approach to Fernandes & Feiner [1] where they interpolated and faded between images. The author found the VCA method to be more favourable, as it was easier to control and interpret the level of FOV constriction. The

VCA script itself was applied to the main player camera. The vignetting amount was determined by a decimal number between 0 and 1, 0 being no vignetting, and 1 meaning complete coverage of screen (see Figure 5-1). The author wrote a script to automatically set the vignetting value based on the avatar's translational and rotational velocity.

Dynamic FOV Manipulation Implementation

The Dynamic Field-Of-View Manipulation script (henceforth known as "DFOV") monitors the movement of the main player character. In doing so, the character's translational and rotational velocities are calculated. Rotations and movements, which are the result of input from the ORDK2 head-tracking, are not included in DFOV calculation. This is because the resulting movement is almost directly correlated with the user's actual head and neck movement (assuming low-latency). This action contributes very little to inducing VR sickness as there is little sensory mismatch between what the participant is physically doing, and what they are perceiving. Rotating the player character via XBox Controller however, contributes to DFOV calculation as it is not the result of an actual movement by the participant. The variables for DFOV are as follows are outlined below. The values were chosen based on tests carried out when developing the trial VR application.

- ***vig*** refers to the vignetting value on the VCA script (value between 0 and 1 where 0 is full FOV and 1 is no FOV).
- ***vigMin*** refers to minimum vignetting value of constriction. 0.2 ($\tilde{8}0$ degrees FOV).
- ***vigMax*** refers to maximum vignetting value of constriction. 0.7 ($\tilde{3}0$ degrees FOV).
- ***cRate*** refers to FOV constriction rate. This was set to 0.7 degrees per frame at 75fps.
- ***aVel*** refers to angular velocity.
- ***aVelMin*** refers to minimum angular velocity required to trigger DFOV calculation.
- ***aVelMax*** refers to the highest angular velocity.
- ***tVel*** refers to translational velocity.
- ***tVelMin*** refers to minimum translational velocity required to trigger DFOV.

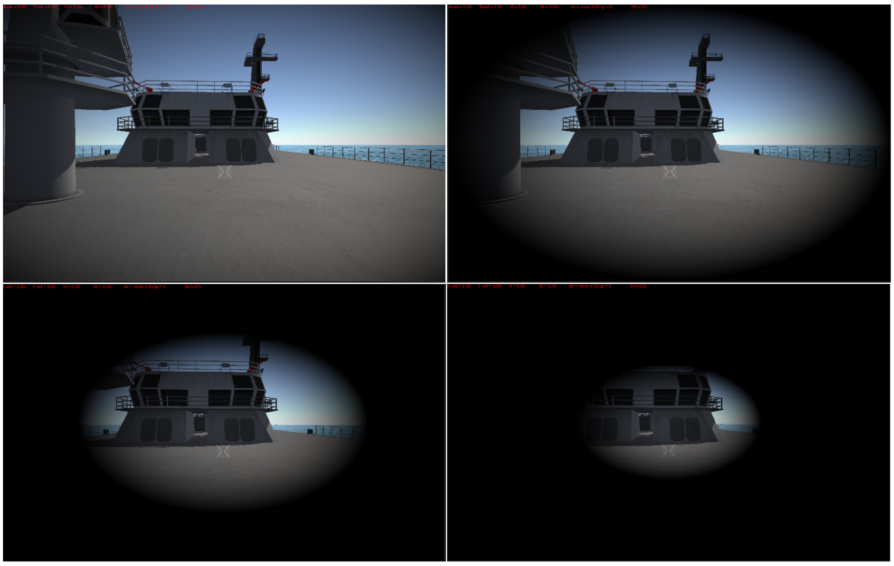


Figure 5-1: Top-left: vignetting = 0.3, Top-right: vignetting = 0.5, Bottom-left: vignetting = 0.7, Bottom-right: vignetting = 0.85

- ***tVelMax*** refers to the highest translational velocity.

If any of the velocities (***aVel*** or ***tVel***) exceeds their maximum velocities (***aVelMax*** and ***tVelMax*** respectively), then their value would equal their maximum counterpart.

The final ***vig*** value (between 0 and 1 inclusive) is calculated in proportion to the amount of rotation and translational movement.

$$vig = \frac{((Angular \times 0.8) + (Translational \times 0.8))}{2}$$

The following block of pseudocode shows how the ***Angular*** value is calculated. ***Angular*** value is clamped based on the values of ***aVelMin*** (floor) and ***aVelMax*** (ceiling). If this does not achieve minimum velocity, the influence of angular rotation is nullified. The influence of translational velocity (***Translational***) is calculated the same way.

if (aVel $\geq$ ***aVelMin and aVel*** $\leq$ ***aVelMax) Angular*** $= \frac{aVel}{aVelMax}$

else if (aVel $\geq$ ***aVelMax) Angular*** $=$ ***aVelMax***
else Angular $=$ ***0***

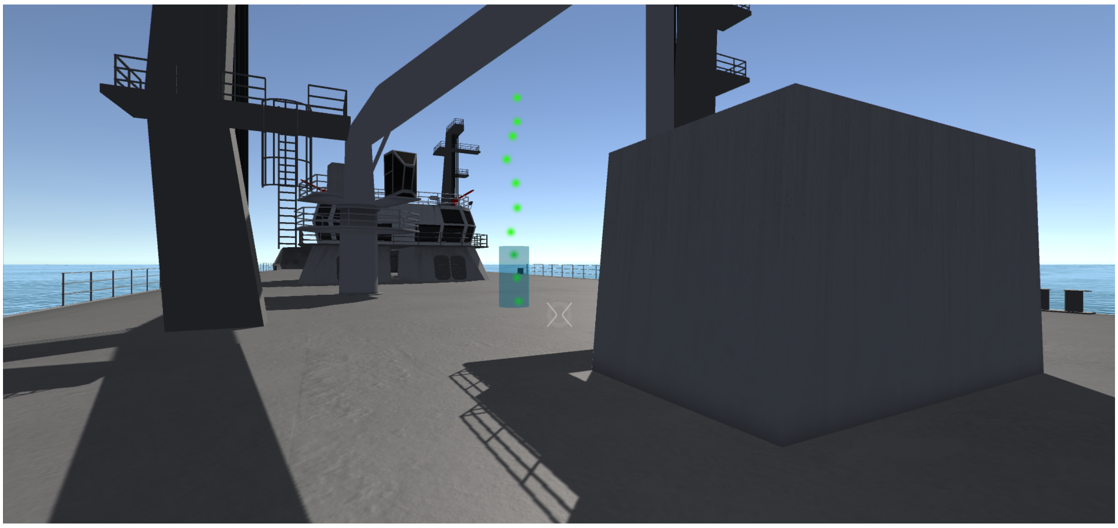


Figure 5-2: Typical game view the participant perceives. The cross-hair in the centre indicates the orientation of the virtual body. The way-point is indicated by the transparent-blue cylinder, with a green particle effect emanating from the base.

$\boldsymbol{if\ (tVel \geq tVelMin\ and\ tVel \leq tVelMax)\ Translational} = \frac{tVel}{tVelMax}$
$\boldsymbol{else\ if\ (tVel \geq tVelMax)\ Translational = tVelMax}$
$\boldsymbol{else\ Translational = 0}$

5.3.3 Virtual Avatar and 'Stumbling'

The virtual avatar consisted of a camera which sat at a simulated height of 1.6 metres above the base of the character. As there was no modelled humanoid avatar, a cross-hair marker was placed in front of the camera which was made to match the orientation of the virtual body. This allowed users to see which way it was oriented, enabling them to easily move their head as well as move around.

The 'stumbling' mechanism was based on a script which calculated the tilt angle (***ang***) between the up-vector (normal) of the player character, and the normal vector of the floor plane. The author specified a minimum angle, maximum angle, and push force (***angMin***, ***angMax*** and ***pForce*** respectively). If ***ang*** was between ***angMin*** and ***angMax***, then actual push force (***aPForce***) and stumble direction (***sDir***) was calculated.

aPForce determines the push force on the character. This in turn determines how fast and hard the character stumbles. ***sDir*** determines the direction in which the character stumbles, categorised as left, right,forward, back or none. The 'x' (left and right) and 'z' (forward and back) directional axis for the player character would be affected by ***aPForce***. For example, if the character was facing towards the front of the deck, and the ship began to rock to the left, the character would begin stumbling left. The force was reduced if the player attempted to move against the stumble direction, i.e. direct the character to go right on the controller. Figure 5-3 is a visualisation showing the character on a relatively even plane. When the plane tilts above tolerable levels, the visualisation line showing the normal of the plane goes red (figure 5-4, indicating the opposing forces are now being operated on the character. The direction of stumbling is shown by a white line. ***aPForce*** itself was the result of magnitude of the tilt, i.e:

$$\boldsymbol{if\ (ang \geq aMin)\ aPForce = pForce} \times \frac{ang - angMin}{angMax - angMin}$$

sDir was decided by calculating the projected (xyz to xz plane) angle between the character's forward direction and the direction of the floor plane normal. Each possible stumble direction is specified as 90 degree cones of view, i.e. if calculated relative direction is within a 90 degree cone in front of the character, then ***sDir = forward***.

To further simulate the sensation of stumbling, a mild head-bob was applied, and was directly related to ***aPForce*** in its magnitude. Head-bob is defined as a randomised translation of the camera from its original position along the characters x and y-axis, with movements smoothed over time. Head-offset (distance of camera from the participant's actual head position in VR space) was clamped at 0.2 metres in any direction. In order to prime participants that stumbling was imminent, the cross-hair shook accordingly, signifying that the character was stumbling.

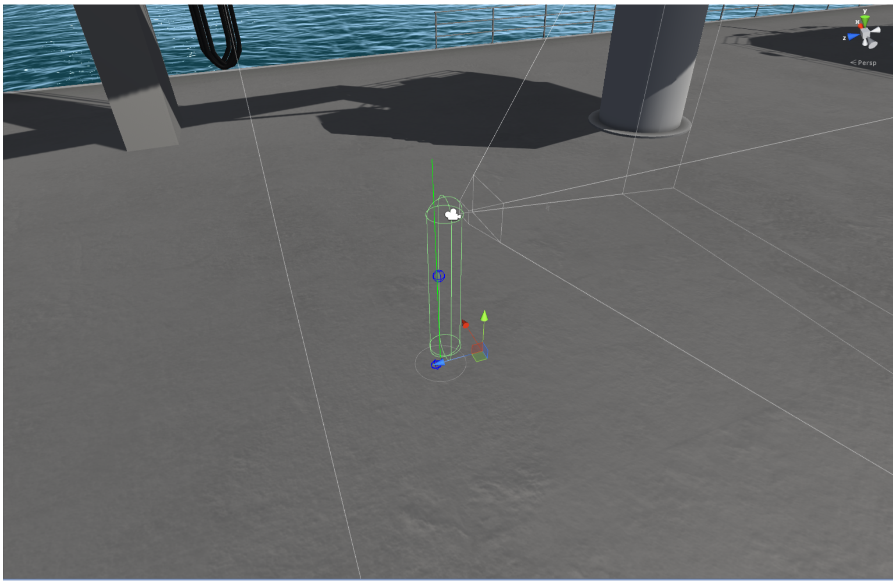


Figure 5-3: Visualisation of the detection of the plane's tilt relative to the player character (represented as a capsule). The solid green line originating from the foot of the character visualises the tilt.

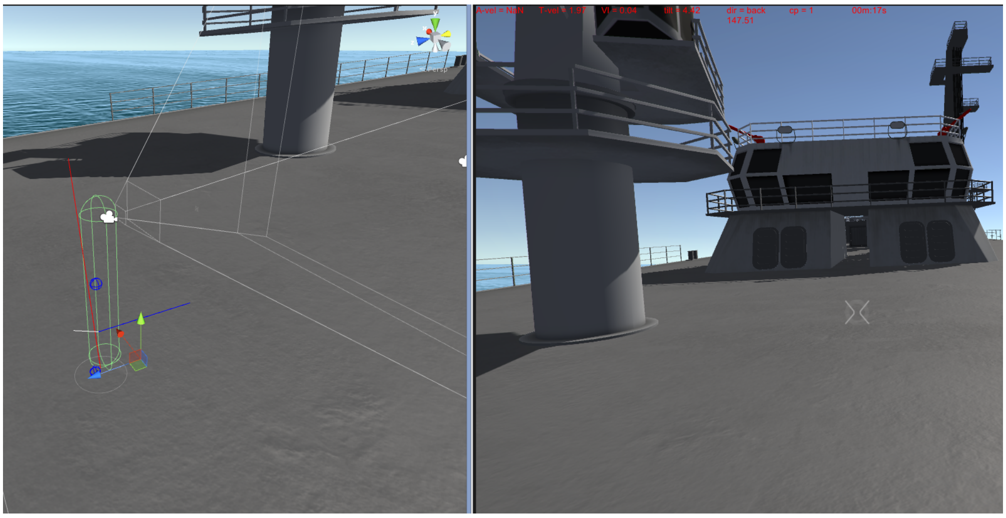


Figure 5-4: The left image shows a visualisation of the character (represented as a capsule) when the plane tilt limit exceeds tolerance, forcing the character to begin 'stumbling'. The small white line at the bottom of the character indicates the tilt direction. The image on the right shows the view from the first person perspective, showing the extreme level of tilt the ship needed in order to for the character to begin stumbling.

5.4 User Study

This study required participants to walk around a VE and follow a series of way-points. When they arrived at a way-point the next would appear, introducing an aspect of exploring and searching. After a period of time, the environment would change to cause the virtual avatar to begin stumbling. Currently, in VR guidelines [2], this kind of animation and control of the camera is avoided. The purpose of this study was to observe whether FOV constriction would help to reduce VR sickness, even when the character is stumbling.

5.4.1 Pilot Study To Define Constriction Parameters

Due to time constraints, it was decided that there would only be one condition in the pilot study. In a similar method as in the paper by Fernandes & Feiner (2016) [1], a pilot study was conducted to determine at what point participants began noticing a change in FOV and at what point FOV constriction became too distracting.

The participant was at first asked to simply put on the ORDK2 and instructed on how to use the XBox controller to move around the environment. However, movement was not required for the first part of the study. The VE they were placed in was a static version of the ship environment described in Section 5.4.4. They were instructed simply to look around and let the experimenter know if they spotted any change in their visual field. Every 5 seconds, the experimenter increased FOV constriction, i.e. the vignetting value on the VCA script (see Section 5.3.2), by an increment of 0.05. The decrease of FOV was displayed at a constant constriction rate. Once the participants spotted the change in FOV, the experimenter stopped and further elaborated that he was decreasing the field of view. They were then asked to begin walking around the VE. They were informed that the experimenter would continue to reduce the FOV, and were told to convey the point at which the FOV became too distracting or uncomfortable.

A total of 11 participants took part in the pilot study. Each FOV change was categorised according to transition between previous FOV and new FOV as the change was displayed over time rather than instantly. They were represented in the analysis as a key-pair value, shown in Table 5.1.

The two interesting values were denoted as "ideal FOV" (when they first noticed constriction in FOV) and "distracting FOV" (when FOV reduced to the point where it became too distracting). A mean score was taken for each, showing that the score for ideal FOV was ***7.91 (SD = 3.015)*** and score for distracting FOV was ***10.82 (SD = 2.639)***. The means were then rounded to the nearest category, with ideal FOV equalling

Table 5.1: Table showing categories of FOV constriction changes, represented by the change in the vignetting value

Key	Vig	Key	Value
1	0.30 - 0.35	8	0.65 - 0.70
2	0.35 - 0.40	9	0.70 - 0.75
3	0.40 - 0.45	10	0.75 - 0.80
4	0.45 - 0.50	11	0.80 - 0.85
5	0.50 - 0.55	12	0.85 - 0.90
6	0.55 - 0.60	13	0.90 - 0.95
7	0.60 - 0.65	14	0.95 - 1.00

8 (or 0.65 - 0.7) and distracting FOV equalling 11 (or 0.8 - 0.85). The maximum value from each range was used, making vignetting value of 0.7 the ideal maximum FOV constriction. This was because the maximum constriction could only be achieved when the player's angular and translational velocity values are at near-maximum. The two images on the bottom row of Figure 5-1 show the mean ideal and distracting FOV. The ideal FOV was therefore used in the main study.

Due to time constraints and limited availability of participants, a second constriction condition using the distracting FOV was not included in the main study. It was shown in Fernades & Feiner (2016) [1] that while there were no significant differences to presence there were increased reports of the VE "becoming dimmer" in the distracting FOV condition. Participant's accounts of noticing the constriction effect were no different between ideal and distracting FOV in their study. For the sake of limiting complexity, only one constriction condition was created using the ideal FOV value, alongside the "no constriction" condition.

5.4.2 Experiment Design

The main study used a two-session mixed experimental design, where each participant completed two VR trials. In each trial, either FOV constriction was used, or it was not present at all. The order of the conditions varied, where half of the participants had no constriction in the first trial (**N1**) and FOV constriction in the second trial (**C2**) and the other half did the trials the other way round, i.e. constriction first (**C1**) and no constriction second (**N2**). Participants were required to spend a minimum of 9 minutes, and maximum of 14 minutes in the VE as this would provide sufficient VR exposure while also being able to complete both trials in the time allotted. In the previous study in Chapter 4 it was concluded that 2-3 minutes was not enough time to elicit a

Figure 5-5: Figure showing the VE, a long with the distribution of way-points.

physiological response. When trailing software utilising the OR DK2, typically users would be exposed in for around 8-12 minutes. They were given a mandatory 15-minute break between trials in order to help them recover from any VR sickness effects, and in turn measure whether effects from the first trials were lasting.

5.4.3 Participants

Overall 30 Participants took part, 28 of which provided usable data. 11 were discounted due to either early drop-out due to high discomfort (i.e. before 200 seconds), high scores in the first pre-exposure SSQ, or they took too long to perform the tasks (more than 200 seconds to reach the first four checkpoints). These participants were pre-emptively excluded for safety concerns, particularly those participants who reported discomfort before they commenced the actual VR session. All participants were students from the University of Bath. They were recruited via flyer advertisements both digitally and posted around the campus and were offered to be entered into a prize draw for a £100 retail voucher as an incentive to take part. Ethical approval was sought through the University of Bath Computer Science Department.

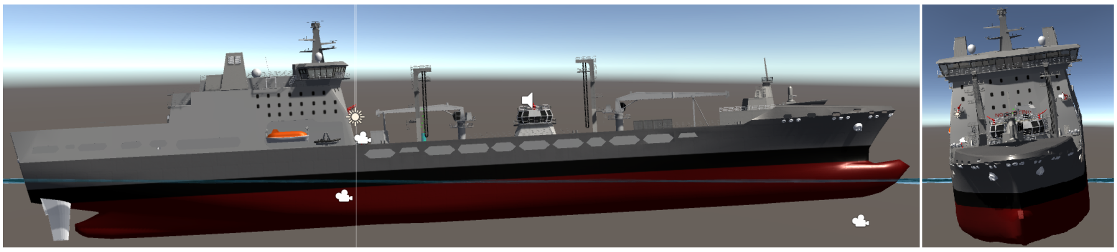


Figure 5-6: The left image shows the ship tilting at maximum pitch. The right image shows the ship tilting at maximum roll.

5.4.4 Virtual Environment

The participants were asked to navigate around the deck of fuel tanker ship whose exterior was adequately modelled for realism. The VE itself simply consisted of the tanker surrounded by the ocean and a skybox. Participants were asked to follow a series of way-points which appeared one at a time. The waypoints were represented by a transparent blue cylinder and a green particle effect (figure 5-5). As the way-points would appear in a pseudo-randomised location, they sometimes were not within line-of-sight from the participant's current position. Altogether there were 40 way-points in the scene. The experimenter generally stopped at 32. However, if participants performed faster than expected, e.g. they got 32 way-points in 7 minutes, then the experimenter would allow them to continue in order to extend their time in the VE.

The ship itself would rock and sway subtly towards the beginning of the trial. This was a constant and symmetrical animation curve. After a specific time (3 minutes 20 seconds), the ship began to rock and sway more erratically, with the deck appearing to tilt (see figure 5-6). This was done on a pseudo-randomised animation curve. A script written by the author calculated the tilt of the deck relative to the character. If the tilt exceeds a minimum angle, the character would begin to 'stumble' (see Section 5.3.3).

5.4.5 Procedure

When the participants arrived, they were given a brief with a consent form (see Appendices). The brief outlined that they would be asked to perform a couple of VR trials for approximately 10 minutes each. They were also told that they could withdraw themselves and their data at any time. Most importantly, they were informed that they should let the experimenter know as soon as they become uncomfortable, sick or nauseous as a result of taking part so that the trial could be terminated. It was made clear to them that VR applications could induce symptoms similar to motion sickness, and that it varied from person to person. However, the participants were not informed of the true nature of the study until after the experiment was over. The study was advertised as "Sit back and walk: Movement In Virtual Reality" (see Appendices). They were also informed that the trial would be over when the experimenter said so. His criteria for this was generally if they completed 32 way-points within 8-12 minutes, or if the participant was near the 10-minute mark. As mentioned in Section 5.4.4, the experimenter would allow them to search for up to 40 way-points if they felt the participant was unusually fast at finding them. The brief also had a questionnaire of 3 items. The questions related to proficiency with game controllers, experience with HMDS and known susceptibility to motion sickness.

The experimenter then repeated the basics of the task, the control scheme for moving around the virtual environment and reiterated the fact they could ask to stop the trial at any point. For each trial, the participants were required to fill out an SSQ. Once they wore the Oculus Rift, they remained in a stationary position for between 30 seconds to 2 minutes (depending on participants) to get acclimatised to the virtual world. Once they were comfortable to continue, they began the trial. The first way-point was directly in front of them. At around the 180-second mark, the participant was informed that the ship would start to rock and sway more and may hinder their movements.

One other measure used was the Discomfort Score (see figure 5-7)[1, 61]. After every fourth way-point, the application would pause (though the participant could still move their head freely). A pop-up window appeared with the statement "On a scale of 0-10, 0 being how you felt coming in, 10 being that you want to stop, where are you now?". Underneath it was a scale between 0 to 10, which the participant could select using specific buttons on the controller. If at any point the participant chose the option '10', then the trial would automatically be discontinued. The same was true for if the participant simply indicated their desire to stop. If participants terminated due to discomfort, their final discomfort score was set to 10 by the experimenter during analysis.

Once the trial had finished, the participants then filled out a second SSQ, followed by the Presence Questionnaire [20]. Questions relating to haptic feedback were omitted from this version. All questionnaires were implemented digitally, where the participant filled them out on-screen using drop-down menus which contained all possible answers.

If this was the first trial, the participant was asked to go for a minimum 15-minute break. When they came back, they were asked if they were OK to continue. If so, the process was repeated again for the second trial. After both trials were over, the participant was asked whether they noticed any difference between the trials. Their

Figure 5-7: UI which appears every 4 way-points. This allows the participant to enter their level of discomfort. Discomfort Score is recorded when the user accepts input

observations were recorded, including if they noticed FOV constriction, if one trial was seemingly more comfortable than the other, or if they felt it was easier to navigate. After this, the participants were informed of the true nature of the experiment. Any other observations after this pointed were noted by the experimenter.

5.5 Hypotheses

The hypotheses formed are based on which conditions the participants took part in, as well as the order in which they did them. The following hypotheses were tested against the study results.

H1: Significantly more discomfort will be reported in **N1** (first trial with no constriction) than **C1** (first trial with constriction). It is predicted that using FOV constriction will significantly reduce VR sickness.

H2: Significantly more discomfort will be reported in **N1** (first trial with no constriction) than **C2** (second trial with constriction). Not only should this be because the FOV constriction should reduce VR sickness, but because the previous exposure should help to acclimate the participant to being in the VE. There is also the danger, however, that the first session may have given a more adverse experience to the participant (hence the 15-minute break is enforced).

H3: Significantly more discomfort will be reported in **N2** (second trial with no constriction) than **C2** (second trial with constriction). Participants who may have benefited from the constriction in the first session are more likely to suffer from the lack of DFOV constriction in the second session, regardless of prior exposure. Those who did not have constriction in the first session may correspondingly derive more benefit from its introduction in the second session.

H4: There will be a significantly higher reported presence scores in the **N** (no constriction) conditions compared to the **C** (constriction) conditions.

5.6 Results

This section describes the method by which the results were derived for each measure. The analysis was done to investigate each hypothesis, as well as some further analysis to evaluate the validity of the study design. Standard deviations are shown to be quite high as the study was underpowered (see Figure 5-8)

Total SSQ Scores

Condition		NauseaTotal	OculoMotorTotal	DisorientationTotal	Total
C1	Mean	5.73	5.67	4.47	11.80
	Std. Deviation	4.008	4.467	3.889	8.377
C2	Mean	5.31	5.15	3.38	9.69
	Std. Deviation	5.056	4.723	3.664	8.645
N1	Mean	3.85	4.08	2.46	7.54
	Std. Deviation	3.738	3.523	3.017	6.476
N2	Mean	9.07	7.47	7.07	17.33
	Std. Deviation	6.850	5.475	6.053	13.004
Total	Mean	6.09	5.66	4.45	11.80
	Std. Deviation	5.334	4.672	4.600	10.003

Figure 5-8: Table showing the mean Total SSQ scores and standard deviations across all four conditions

Relative SSQ Scores

Condition		Total Difference	Nausea Difference	OculuMotor Difference	Disorientation Difference
C1	Mean	8.87	4.93	3.53	3.40
	Std. Deviation	9.738	4.480	5.249	3.979
C2	Mean	2.46	1.92	.69	.77
	Std. Deviation	2.436	1.754	1.109	1.691
N1	Mean	4.46	2.92	1.62	1.85
	Std. Deviation	4.196	3.013	1.261	2.230
N2	Mean	8.00	3.73	3.60	3.73
	Std. Deviation	8.611	3.751	3.869	4.605
Total	Mean	6.13	3.45	2.45	2.52
	Std. Deviation	7.415	3.547	3.608	3.547

Figure 5-9: Table showing the mean Total SSQ scores and standard deviations across all four conditions

Presence Questionaire Scores

Condition_2		Total	Realism	Possibility to Act	Quality of Interface	Possibility to Examine	Self-evaluation of Performance	Sound
C	Mean	105.86	32.21	20.54	14.75	15.14	10.93	12.29
	Std. Deviation	14.809	6.220	3.786	3.216	2.534	1.762	3.463
N	Mean	107.85	33.96	21.46	14.42	15.15	10.65	12.19
	Std. Deviation	14.206	5.134	3.062	4.197	2.935	2.226	3.868
Total	Mean	106.81	33.06	20.98	14.59	15.15	10.80	12.24
	Std. Deviation	14.420	5.738	3.456	3.688	2.709	1.985	3.629

Figure 5-10: Table showing the mean PQ scores and standard deviations across all conditions

5.6.1 Measures

SSQ Analysis Overview

The original authors of the SSQ [37, 2] defined three subcategories of questions; Nausea, Oculomotor and Disorientation. Nausea (Nscore) relates to questions regarding gastrointestinal distress, i.e. nausea, salivation, stomach-related. Oculomotor (Oscore) refers to head and vision-related items on the SSQ. Disorientation (Dscore) relates to items on vestibular imbalances such as dizziness and vertigo. Finally, analysis of mean differences between pre and post-exposure SSQs yields a relative change in SSQ as the result of exposure. A relative SSQ (RSSQ) is also provided, showing the mean difference in SSQ scores after the first trial and before the second trial, i.e. SSQ scores before and after the break.

PQ Analysis Overview

The Presence Questionnaire used was an updated version of the original Witmer and Singer Questionnaire [20]. A total of 22 questions were used [62]. Questions 23 and 24 were removed as they related to haptic feedback, which not used in this study. A total score (**pTotal**) and a sum of all of the categories were used in the analysis. The questionnaire categories were as follows:

- Realism (**pR**) (similarity to real-life reference)
- Possibility to Act (**pPA**) (ability to explore and manipulate VE)
- Quality of Interface (**pQI**) (negative questions on problems caused by software or hardware)
- Possibility to Examine (**pPE**) (ability to examine objects from multiple angles)
- Self-evaluation of Performance (**pSP**) (competence in performing tasks in VE)
- Sounds (**pSound**)

Discomfort Score Analysis

An average discomfort score (ADS) was computed for each trial [1, 61]. As each recording of a DS score was taken at irregular time intervals, an average rise (or fall) in DS was used where DS changed from the previous recording. This was a different approach to the method of calculating the total time-weighted average DS used in the study by

Fernandes and Feiner [1], who sampled the DS score at 1-second intervals until the time of the final DS recording.

At each recording (***i***), unless it was the first check point, the weighted discomfort score at ***i*** (denoted as ***WDS***$_i$) was calculated. Rather than assuming that the players discomfort level between recordings remained the same, an average change in DS was taken into account instead, reducing the likelihood of underestimating the progression of discomfort levels. Where ***DS***$_i$ is the DS at recording ***i***, and ***T***$_i$ is the time at recording ***i***. The weighted discomfort score was calculated in relation to the previous discomfort score and it's time index to reflect an average rate of change between DS score recordings.

$$WDS_i = \frac{(DS_i + DS_{i-1}) \times (T_i - T_{i-1})}{2}$$

The average discomfort score (***ADS***) reflects the average progression of the discomfort score for each participant i.e. the rate of increase or decrease in the users' discomfort during the trial. Using the total sum of all ***WDS***$_i$ values (denoted by ***TotalWDS***), ***ADS*** could be computed, where ***Tstop*** refers to time at last recording in the trial:

$$ADS = \frac{TotalWDS}{Tstop}$$

In the research by Fernandes and Feiner [1], they introduced a measure called Relative Discomfort Score (RDS). Due to their high drop-out rate, only a fraction of the participants were able to complete the task. They posit that "for example, two participants could finish the session with the same ADS and SSQ scores, yet one participant could have spent much more time in the VE before finishing." RDS was proposed to take time spent in the VE into account, regardless of whether they finished or not. As mentioned previously anyone who dropped out before the experimenter asked them to stop, had their final DS automatically recorded as '10' at the time at which they asked to stop.

RDS calculation uses the longest time taken by anyone to complete the task (denoted by ***Tmax***). For each trial, the DS score between ***Tstop*** and ***Tmax*** is assumed to be the same score as the last recorded DS (denoted as ***DSstop***), therefore:

$$RDS = \frac{TotalWDS + DSstop \times (Tmax - Tstop)}{Tmax}$$

The results of ADS and RDS for each trial are shown in Figure 5-11

Participant	Condition	Time Stopped	Last Score	Total Score	ADS	RDS
1	C1	634.30	10	2602.18	4.10	5.55
1	N2	375.00	10	1781.54	4.75	7.66
2	C1	657.75	10	2834.83	4.31	5.55
3	N1	814.92	5	2157.83	2.65	2.72
3	C2	691.70	3	1184.65	1.71	1.94
4	N1	784.82	0	283.75	0.36	0.34
4	C2	696.04	1	437.16	0.63	0.69
5	C1	839.87	1	238.07	0.28	0.28
5	N2	653.66	0	0.00	0.00	0.00
6	C1	608.79	5	1394.28	2.29	3.04
6	N2	485.46	5	1332.70	2.75	3.70
7	N1	567.69	7	1207.70	2.13	3.71
7	C2	406.28	3	649.36	1.60	2.32
8	N1	567.63	3	1174.96	2.07	2.37
8	C2	618.99	4	1383.70	2.24	2.70
9	C1	709.51	1	510.73	0.72	0.76
9	N2	742.83	6	2799.72	3.77	4.03
10	C1	840.17	7	1900.60	2.26	2.26
10	N2	303.08	10	725.16	2.39	7.26
11	N1	770.72	0	0.00	0.00	0.00
11	C2	475.38	0	0.00	0.00	0.00
12	N1	375.05	10	1086.03	2.90	6.83
13	C1	150.51	10	532.34	3.54	8.84
13	N2	660.44	0	151.17	0.23	0.18
14	C1	538.74	1	135.82	0.25	0.52
14	N2	695.35	3	661.64	0.95	1.30
15	N1	517.65	10	1560.59	3.01	5.70
15	C2	612.98	0	62.75	0.10	0.07
16	N1	673.12	0	0.00	0.00	0.00
16	C2	779.27	7	1428.94	1.83	2.21
17	C1	405.74	10	1566.90	3.86	7.04
17	N2	651.21	10	1760.10	2.70	4.34
18	N1	452.69	1	60.24	0.13	0.53
18	C2	554.18	8	1489.22	2.69	4.50
19	C1	211.07	10	711.37	3.37	8.33
19	N2	385.06	10	824.40	2.14	6.40
20	C1	586.60	9	2172.93	3.70	5.30
20	N2	683.89	10	3646.44	5.33	6.20
21	C1	699.17	1	520.93	0.75	0.79
21	N2	610.71	0	413.11	0.68	0.49
22	N1	469.19	10	1896.86	4.04	6.67
22	C2	278.55	10	1031.07	3.70	7.91
23	N1	566.80	1	270.56	0.48	0.65
23	C2	575.85	1	247.13	0.43	0.61
24	C1	650.57	1	730.33	1.12	1.09
24	N2	558.85	4	1025.10	1.83	2.56
25	C1	612.38	6	1402.05	2.29	3.30
25	N2	584.51	5	1910.37	3.27	3.80
26	N1	631.88	6	1132.28	1.79	2.84
26	C2	368.24	10	921.68	2.50	6.71
27	N1	672.38	3	930.79	1.38	1.71
27	C2	576.18	3	1018.15	1.77	2.15
28	C1	527.01	10	2343.35	4.45	6.52
28	N2	349.82	10	1407.17	4.02	7.51

Figure 5-11: Table showing total cumulative DS scores for each trial, as well as RDS and ADS scores

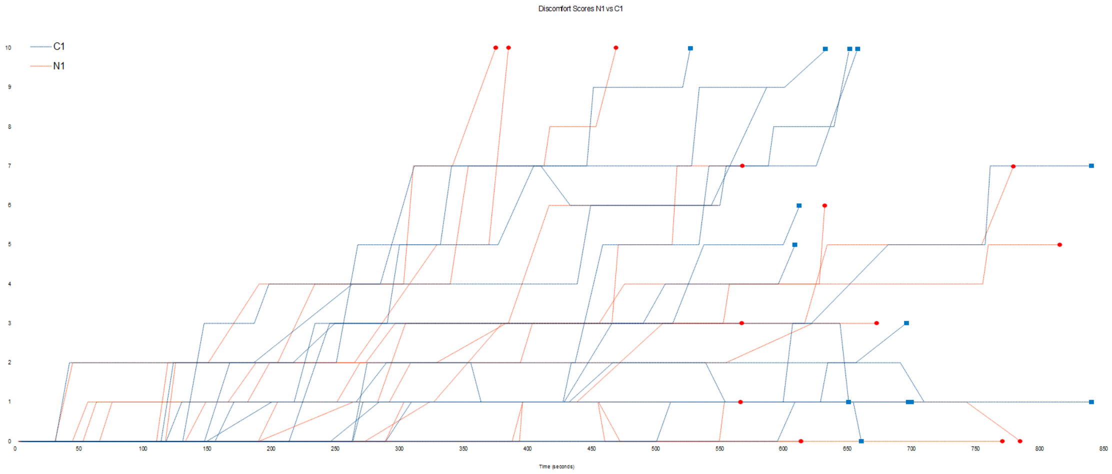


Figure 5-12: Graph showing the rate of increase in Discomfort Scores for each participant in the N1 and C1 conditions. Shapes show the finishing point for each participant

5.6.2 H1: N1 vs C1 Discomfort

Using an independent sample t-test to compare ADS scores of N1 and C1, there were no significant differences in **ADS** (**t(26)= -1.613, p= 0.119**) and **RDS** (**t(26)= -1.89, p= 0.209**) values. There were no significant differences in the **total relative SSQ** scores (**t(25.705)=-1.516, p= 0.142**), **relative Nscore** (**t(26)= -1.288, p= 0.209**), **relative Oscore** (**t(26)= -1.052, p= 0.303**) and **relative Dscore** (**t(26)= -1.534, p= 0.137**) (see Figure 5-12).

H1 is therefore rejected, indicating that even without the influence of practice-effect, constricting FOV did not yield significantly lower SSQ and Discomfort scores.

5.6.3 H2: N1 vs C2 Discomfort

Using an independent sample t-test to compare N1 and C2, there were no significant differences in **ADS** (**t(23)=0.023, p= 0.982**) and **RDS** (**t(23)=-0.032, p= 0.975**) values. There were no significant differences in the **total relative SSQ** scores (**t(22.242)=-0.719, p= 0.48**), **relative Nscore** (**t(24)=-0.838, p= 0.411**), **relative Oscore** (**t(24)=-0.659, p= 0.517**) and **relative Dscore** (**t(24)=-0.701, p= 0.490**) (see Figure 5-13).

H2 is therefore rejected showing that even with the participant already having prior exposure to the VE, the rate of increase in SSQ and Discomfort did not change in their second trial.

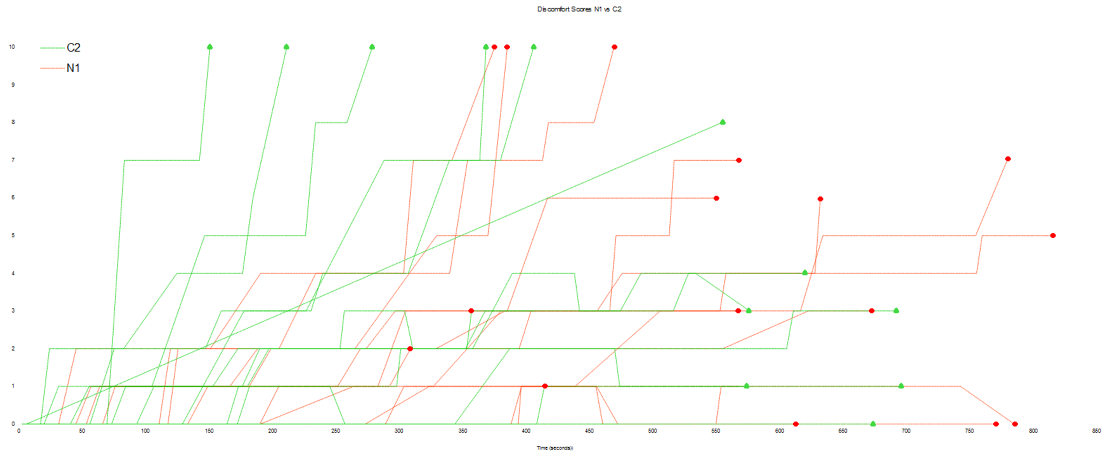


Figure 5-13: Graph showing the rate of increase in Discomfort Scores for each participant in the N1 and C2 conditions. Shapes show the finishing point for each participant

5.6.4 H3: N2 vs C2 Discomfort

There were no significant differences in **ADS** (**t(24)=1.617, p= 0.120**) and **RDS** (**t(24)=1.258, p= 0.220**) values. There were no significant differences in the **total relative SSQ** scores (**t(22.242)=-0.719, p= 0.480**), **relative Nscore** (**t(26)=-0.838, p= 0.411**), **relative Oscore** (**t(26)=-0.659, p= 0.517**) and **relative Dscore** (**t(26)=-0.701, p= 0.490**) (see Figure 5-14).

H3 is therefore rejected, indicating that even prior exposure and practice in either condition did not make a difference to the rate of increase in SSQ and Discomfort scores.

5.6.5 H4: N vs C Presence

Independent samples t-test between combined **N** (**N1 + N2**) and **C** (**C1 + C2**) yielded no significant differences in all presence scores: **pR** (**t(52)=1.129, p= 0.264**), **pPA** (**t(52)=0.991, p= 0.326**), **pQI** (**t(52)=-0.320, p= 0.751**), **pPE** (**t(52)=0.015, p= 0.988**), **pSP** (**t(52)=-0.500, p= 0.619**), **pSound** (**t(52)=-0.093, p= 0.926**), **pTotal** (**t(52)=0.504, p= 0.617**).

H4 is therefore rejected. This is a desired result as the aim was to yield a reasonable presence score across all conditions, where it was hoped that the presence of FOV constriction would not become distracting. An overall mean score of **106.81 (SD = 33.06)** out of a total possible score of **154** indicates a very positive presence score.

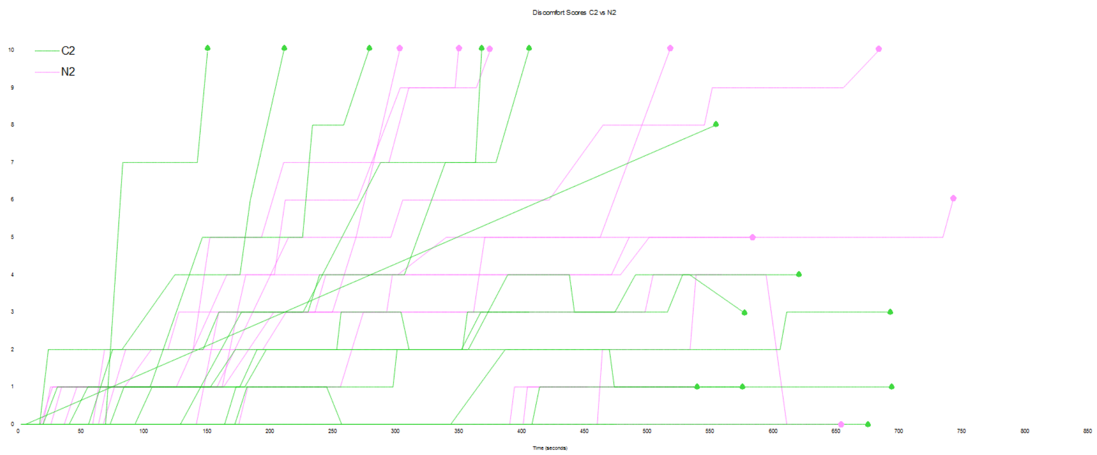


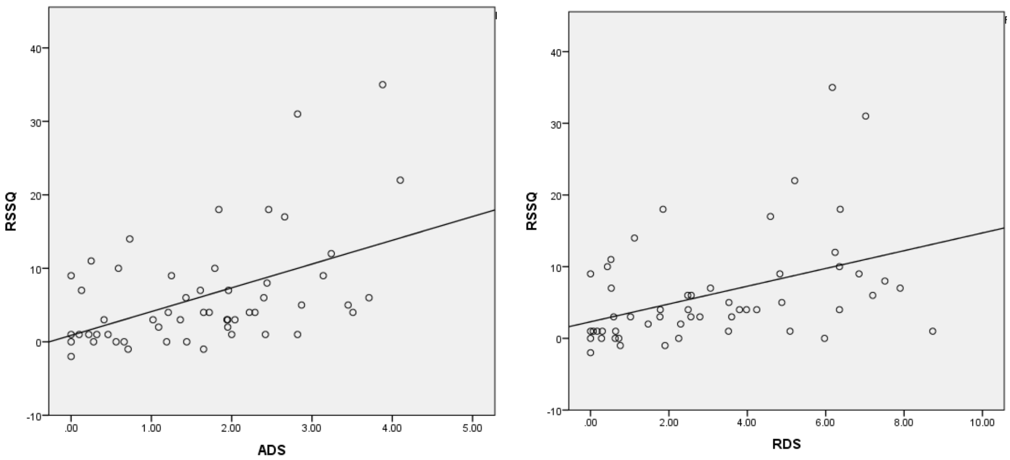
Figure 5-14: Graph showing the rate of increase in Discomfort Scores for each participant in the N2 and C2 conditions. Shapes show the finishing point for each participant

5.6.6 N vs C Discomfort

There were no significant differences in **ADS** (**t(52)=-0.067, p= 0.947**) and **RDS** (**t(52)=-0.075, p= 0.940**) values. Independent samples t-test between combined **N** (**N1 + N2**) and **C** (**C1 + C2**) yielded no significant differences in all relative SSQ scores: **total relative SSQ** scores (**t(53.292)=0.232, p= 0.817**), **relative Nscore** (**t(54)=-0.187, p= 0.853**), **relative Oscore** (**t(54)=-0.478, p= 0.635**) and **relative Dscore** (**t(54)=-0.713, p= 0.479**) (see Figure 5-14).

5.6.7 Correlating RDS Scores with Relative SSQ Scores

A correlation test was performed to observe whether the relative rise in all RSSQ (see Figure 5-9) scores correlated to the average rate of increase in corresponding ADS and RDS scores. A Pearson's correlation test between RSSQ scores and ADS yielded a moderate positive correlation which was statistically significant (**r = 0.488, n = 54, p = 0.0002**). Another Pearson's test between RSSQ scores and RDS yielded a moderate positive correlation which was a statistically significant score [63] (**r = 0.418, n = 54, p = 0.0017**). This shows that there was a relationship between the rise in discomfort and the rise in reported VR sickness, showing that both measures were an accurate representation of the participant's discomfort. See Figure 5-15.



(a) Scatter plot showing correlation between RSSQ and ADS *(b) Scatter plot showing correlation between RSSQ and RDS*

Figure 5-15

5.6.8 Comparing SSQ scores Before and After Break

To evaluate the effectiveness of the break between trials, a comparison was done between post-exposure SSQ of the first trial and the pre-exposure SSQ of the second trials. Figure (5-16) shows the individual results. The mean change in SSQ was **-4.14 (SD= 6.346)**. To get a more accurate representation of whether the break was adequate enough for the participants' symptoms to reduce, the results from the 28th participant were omitted as they were more than 3 standard deviations over the mean. Therefore, the new mean score is now **-3.07 (SD= 2.934)**.

Pearson's correlation test was performed comparing the Trial 1 post-exposure SSQ scores and drop in SSQ after the break. The results showed a significant strong negative correlation of (**r = -0.762, n = 27, p = 0.000004**) (see Figure 5-17). This shows that the drop in SSQ score was greater when the participant's SSQ score was higher before the break, suggesting that it was an adequate period of time between trials for the participant to recover.

5.6.9 Experience Scores

The three questions were categorised as Proficiency With Game Controller (**Game** 1: Not at all; 2: Some experience; 3: A lot of experience), Experience with HMDs (**HMDExp** 1: Not at all; 2: Some experience; 3: A lot of a experience) and Susceptibility to Motion Sickness (**MSick** 1: Not at all; 2 A little; 3: A lot). Mean **Game** score

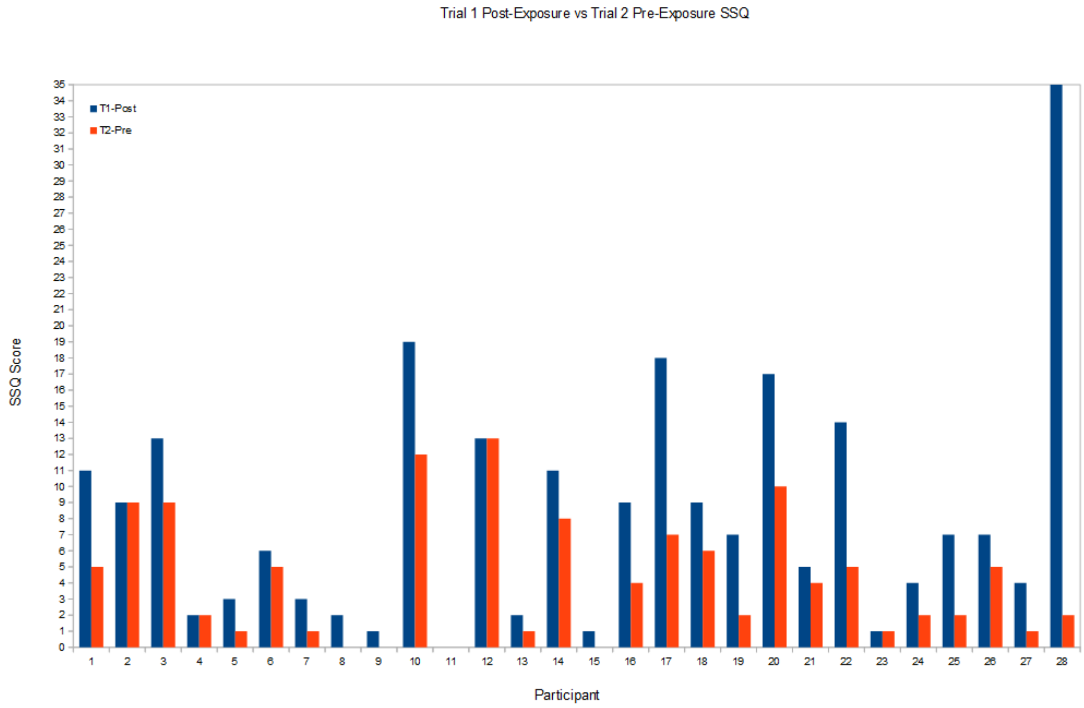


Figure 5-16: Bar chart showing the individual scores for each participant. Blue bar shows their Trial 1 post-exposure SSQ score, and the red bar shows their Trial 2 pre-exposure SSQ score

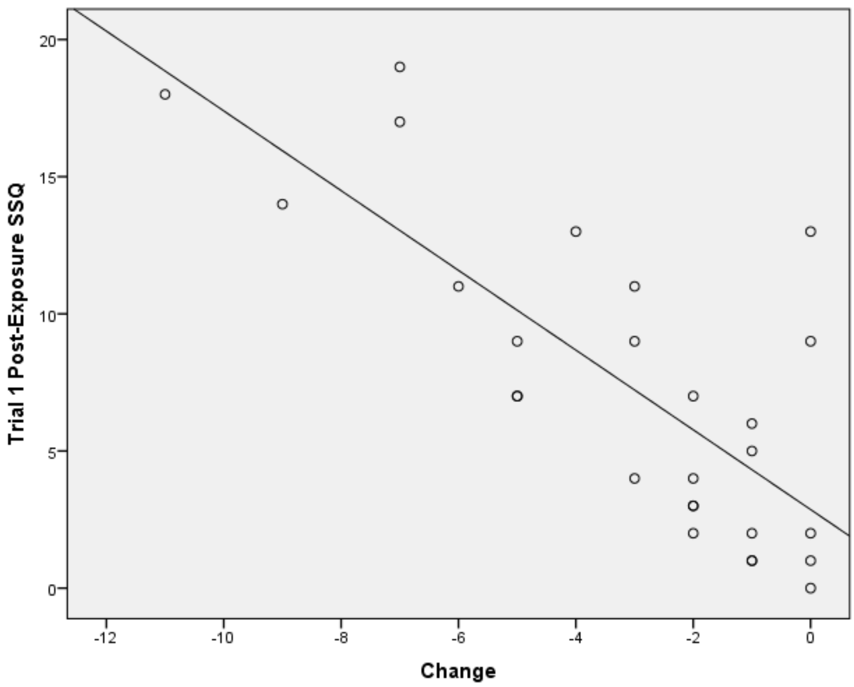


Figure 5-17: Pearson's Correlation showing a significant strong negative correlation between the Trial 1 Post-Exposure SSQ and drop in SSQ after the break

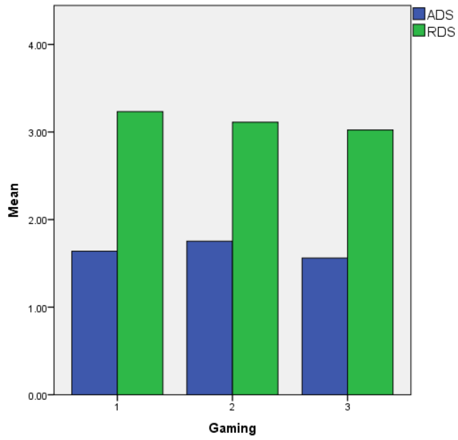


Figure 5-18: Mean ADS and RDS for 'Gaming' question in Experience Questionnaire

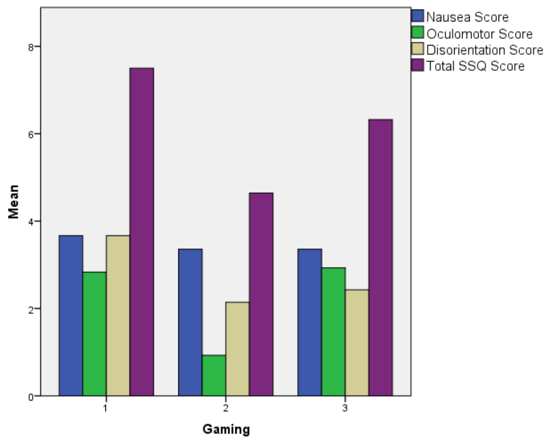


Figure 5-19: Mean SSQ for the 'Gaming' question in Experience Questionnaire

was **2.30 (SD = 0.816)**, **HMDExp 1.46 (SD = 0.503)** and **MSick 1.33 (SD = 0.476)**. To analyse a trend in experience scores and discomfort/simulator sickness, a Pearson's correlation test was performed on the three categories versus RDS and RSSQ scores. There were insignificant weak negative correlations for **Game** vs **RDS** (**r = -0.33, n = 54, p = 0.812**) and RSSQ (**r = -0.35, n = 54, p = 0.802**)). There was a weak positive trend for **HMDExp** versus **RDS** (**r = 0.129, n = 54, p = 0.354**), and an insignificant weak negative trend between **HMDExp** versus **RSSQ** (**r = -0.193, n = 54, p = 0.163**). There was an insignificant weak positive trend between **MSick** versus **RDS** (**r = 0.138, n = 54, p = 0.319**) and **RSSQ** (**r = 0.217, n = 54, p = 0.114**).

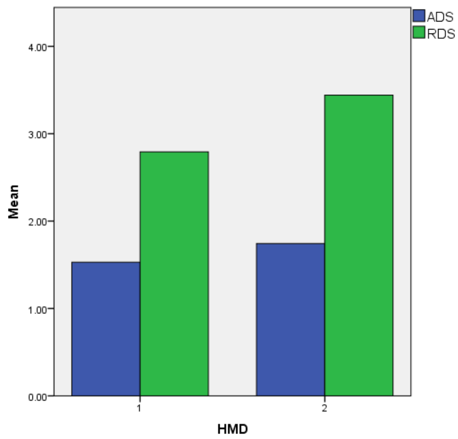


Figure 5-20: Mean ADS and RDS for the 'HMD Experience' question in Experience Questionnaire

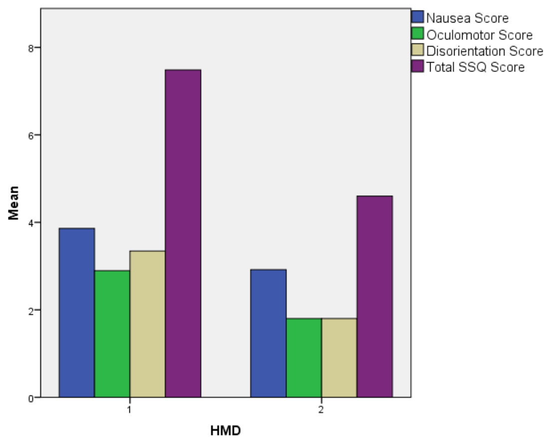


Figure 5-21: Mean SSQ for the 'HMD Experience' question in Experience Questionnaire

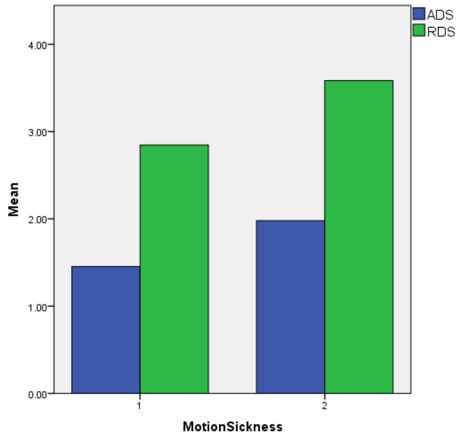


Figure 5-22: Mean ADS and RDS for the 'Motion Sickness' question in Experience Questionnaire

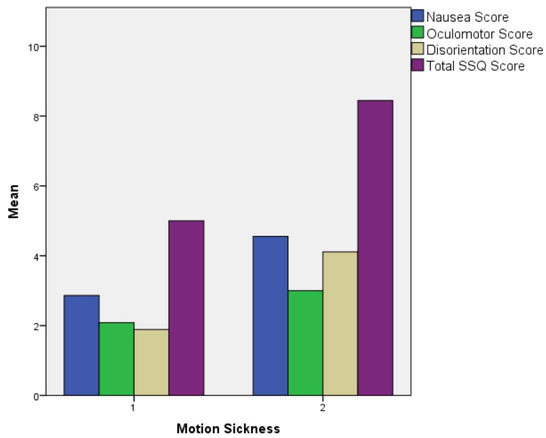


Figure 5-23: Mean SSQ for the 'Motion Sickness' question in Experience Questionnaire

5.6.10 Additional Feedback

C1-N2

Of the 13 participants who were in the C1-N2 sessions, only one participant was able to notice the DFOV effect. That same participant stated that DFOV made them feel more uncomfortable. Two participants felt that they had more control and were proficient in the second trial. Two participants had some trouble getting used to using the controller in the first trial, but by N2 they felt more proficient. One participant stated they thought the second trial was different, but they were not specific as to how.

N1-C2

Of the 15 participants in the N1-C2 sessions, five people noticed the DFOV effect in the second trial. Two participants reported feeling more sick in the second trial, however one of them further elaborated this may have been to do with the fact that they attempted to move their head more in C2 than N1. One participant mentioned they noticed “tunnel vision”, though they did not find it interfered with their experience. One participant had trouble getting used to the controls in the first session.

5.7 Discussion

The study explored whether the current “rules” of VR could be broken by utilising DFOV constriction to reduce VR sickness when participants were subjected to many involuntary movements in VR. It is currently not recommended that the application “takes control” of the VR camera in such a way that would increase the likelihood of inducing VR sickness. These movements range from typical movements, like head-bobbing, to rotating the camera erratically through any means other than input from the user’s direct head movements via accelerometer.

During the task, the participant was asked to navigate around a VE. At a certain point, the plane they were walking on would tilt in a way that would cause the first-person character to engage a ’stumbling’ action, which included shaking of the camera and control of the camera direction temporarily. The aim was to observe whether using DFOV constriction helped to significantly reduce VR sickness, while also retaining the user’s sense of presence.

The results showed that there were no significant differences in participant’s sense of presence, and that the mean presence score was high, indicating the DFOV constriction did not have an impact on presence overall, even though a couple of participants reported it having an adverse effect on their comfort.

5.7.1 Presence

Sense of presence was shown to be consistently high across all conditions. Although this rejects the hypothesis (**H4**), this is beneficial to the aim of the research. One of the biggest problems in using FOV constriction to reduce VR sickness is that it reduces presence [59, 51, 52, 53]. The reason for using dynamic FOV reduction was to attempt to make users almost unaware of the change in FOV, or at the least make it feel more subtle. According to the results of this study this was achieved. Only 6 out of the 28 participants noticed the DFOV constriction, the majority of which (5) noticed it when it was present, only in the second trial. Of those participants, only two were adversely effected by DFOV constriction (a third participant stated their discomfort was more to do with increasing their head-movements while walking). It can be concluded that the DFOV constriction used in this study was subtle enough not to interfere in the participants' experience.

5.7.2 SSQ and Discomfort Scores

The results showed that the use of DFOV constriction did not make a difference in the participant's reported sickness (SSQ) and discomfort levels (Average and Relative Discomfort Scores). Therefore all hypotheses relating to sickness and discomfort would have to be rejected. While DFOV constriction did not interfere with the experience, except for a small number of participants, it seemingly had little difference in reducing VR sickness. This would indicate that this was not an adequate method for reducing VR sickness when the camera is taken control of [2][59][51].

The method for determining the user's sickness and discomfort levels corroborated one another. The method for evaluating ADS and RDS differed from the methods proposed in [1] and [61]. However the method used in this study took into account the potential change over time between recordings. Although this could be remedied by more frequent recordings, doing so with the modality used in this study (pop-up UI in VE) would become too disruptive. The author felt that a discomfort check performed every 4 way-points was adequate. However, other modalities could be used to get a more regular reading, such as verbally asking the participant at regular time intervals. In a reverse fashion, the experimenter could ask the participant to simply indicate when they feel their discomfort was increasing via verbal communication or button press. The participant could adjust a meter in-game at their own discretion. Although slightly more disruptive to game-play, it would give the participant more control, and would hopefully provide a more real-time account of their change in discomfort level. This method may also help to reduce some influence or bias to complete the task. Although each participant was never told how many checkpoints there were, or given a time limit, they inferred that every four checkpoints, the discomfort question would appear. Although this pattern of behaviour was not recorded, the experimenter observed instances where participants were unable to continue but persisted regardless until the next discomfort questionnaire was asked. This was despite the fact that the experimenter made it clear that there was no obligation to finish, and that they can withdraw at any time. In turn, this may have influenced ADS and RDS scores, as participants may have been withdrawing much later than they should have.

A suggested change to the scale of the discomfort score should incorporate negative numbers, e.g. -5 to 10 rather than 0 to 10. There were a few instances in the data where participants actually decreased their score over time. As the discomfort is supposed to be relative to their state when they first entered the VE, it should be reasonable to assume that there is the possibility that they might be more comfortable than their discomfort score in the first recording.

5.7.3 Experience Scores

The participant's proficiencies (experience score) did not have much bearing on their performance as there were no significant relationships between controller proficiency, prior HMD experience or motion sickness susceptibility and relative discomfort scores or relative SSQ scores.

5.7.4 DFOV Constriction Implementation

Assuming the experimental design was sound, this could be due to the parameters used for DFOV constriction. It is possible that the rate of constriction needs to be increased during involuntary movements, i.e. increasing the rate of constriction when the avatar begins to stumble. It could be that the impact of involuntary movements on sensory mismatch had already occurred by the time DFOV had reached full constriction. The level of constriction or screen coverage may also need to differ for stumbling actions. This raises the question as to whether sense of presence would be significantly reduced if the DFOV constriction effect becomes more apparent to participants.

The parameters of DFOV were limited to one universal setting to be used in all experimental conditions for this study. This was done due to the results of the previous study and the pilot study from Fernandes and Feiner [1] showing that the different settings which were used did not have a significant positive impact on VR sickness reduction. However, this now seems like an oversight, as (to the author's best knowledge) trying to reduce VR sickness while purposefully breaking the rules of VR by controlling the camera have not previously been attempted. The one setting for DFOV used in the final study may have been effective for normal static locomotion in VR, but not necessary for more challenging movements.

A feature could be implemented whereby participants can specify and adjust DFOV parameters. For example, if participants found that they were becoming uncomfortable or nauseous, they could increase the amount of FOV reduction. In-turn, if they found the current DFOV constriction settings to be too distracting, they could reduce it. Although this would mean participants were always aware of the effect, it would give a better understanding of ideal settings for different physiological cases. This would make for a very informative pilot study for any future works.

Further study should also be done on whether different parameters need to be applied for various types of environment. For example, there may be a difference in setting for wide, open environments versus a narrow, tight corridor. Other factors might be environmental lighting, static or dynamic environments (e.g. land vs ship on a stormy ocean) and complexity of the scene (e.g. sparse desert vs packed factory). In a sense, DFOV constriction would become truly dynamic depending on the situation. DFOV constriction parameters could also be determined by the type of animation acted on the character. Earlier it was mentioned that using a different DFOV constriction setting for stumbling may have been necessary. This could also be applicable for other animations, such as falling, rolling, and leaping and extended to transitional animations such as opening a door and moving to sit on a chair from a standing position.

Not only should different DFOV parameters (i.e. speed of constriction and maximum FOV reduction) be varied between trials, different settings for different situations should also be tested. For example, walking DFOV can be kept at t a constant constriction rate. However, when the character beings to stumble, constriction rate and maximum FOV reduction could be increased for the duration of the stumbling. There is certainly a larger opportunity for study with these variations alone. This method would also extend to other types of involuntarily movements, such as transitional animations (e.g. sitting on a chair) or falling over. A base DFOV value or multiplier could be set by the participant throughout their trial. For example if a participant felt they were becoming uncomfortable, they should increase the value to constrict faster and reduce the FOV further. Although this may present a problem with maintaining a sense of presence due to the participant's perpetual awareness of the mechanic, it would serve as a great insight in identifying a typical user setting which could be universal in further implementations. Other factors such as the type of environment could justify different parameters for DFOV. Comparisons such as indoor versus outdoor and night versus day could be done for this purpose. Having a mechanic where the user specifies their base DFOV values may reveal a trend as to the settings used by particular users in certain situations. This kind of experiment could be done even with just simple static locomotion.

The avatar's reaction to the tilting ship may have been disproportionate to what the participants may have been expecting. The combination of involuntary movements may have been too unrealistic or too unexpected. Rather than looking at making changes to the visual field, more study should be done on approximating animations or camera movements in such a way that still look convincing while maintaining comfort. If this study was to be replicated, and 'stumbling' was kept as the primary method for testing, then different parameters for stumbling should be explored. Naturally, other movements usually common in first person applications could be tested in a similar fashion, such as falling.

5.7.5 Task and Trial Design

It can be argued that this reasoning can be nullified by an adequate break time. In the study by Fernandez and Feiner [1], the participant carried out each trial one day apart from each other. Although they were in the VE for 15-20 minutes in that study, a day break (including sleep) would most likely mitigate any lasting effect from the first test. In this study, due to time constraints, all trials were carried out in the same 1-hour slot. The participant spent only up to 12-13 minutes in the VE, and was instructed to take a minimum 15-minute break, after which the participant was asked whether they would like to continue onto the second trial. Although the results indicate that the time allotted to each participant was adequate, it did not completely remedy the symptoms some participants experienced at the end of the first trial. Also, it is difficult to determine if there was enough break time as there were no significant differences in SSQ and DS overall conditions, regardless of whether it was the first or second trial.

The task itself was designed to encourage a lot of movement and exploration by the participant, with the way-points pseudo-randomly distributed. The environment used by Fernades and Feiner (Tuscany Demo) was a very open landscape with a building in the middle, where the way-points followed a relatively linear path. In this study, the way-points were not linear, and because of the environmental setting, i.e. deck of a tanker, way-points were occluded by objects such as cranes and crates. In some cases, the user had to walk through enclosed spaces to reach some of the way-points. Although the area of the environment was restricted to the deck on the ship, the author felt there was enough variety to make the task engaging, even though the participant was simply following way-points. The setting also supported the plausibility of the walkable plane tilting at extreme angles (ship rocking on the sea). In normal circumstances, this would be exaggerated, but for the purpose of this study the setting served the task well. Where the design may have faltered was in the longevity of the task. If the participants were kept in the VE for up to 20-25 minutes, for example, the participant's interest may diminish as it was a very limited area. Using an environment such as the Tuscany demo (a garden with a small, fully modelled cottage) may have better served to test this theory. It would also be useful for replicating the findings of previous research. If this study was expanded on in the future, different environments would likely yield different results.

5.8 Conclusion

DFOV constriction was not shown to be effective in reducing VR sickness or discomfort of participants when their character was forced to "stumble" in the virtual environment. This was the case even with the presence of the body-orientation cross-hair which was an added feature to reduce VR sickness. The parameters for DFOV constriction would either have to be adjusted in further testing, or another method should be sought. This study should also be replicated in other varieties of VE to determine whether this too may have an effect. The DFOV constriction however, for the most part, did not interfere with the game-play experience.

Chapter 6

Conclusion

6.1 Overview

This thesis outlines the research in VR performed at a time when consumer VR was just becoming viable. Using iterations (development kits) of the Oculus Rift, the author explored the capability of integrating such technologies into the training applications being developed at the sponsor company. While working on many projects and developing a VR training development framework within the company, the author was able to resolve salient questions pertaining to the use of consumer HMDs in training.

The focus began on researching facets of training where consumer HMDs would be most viable; conducting user studies and collecting information on what benefits and barriers there were to using VR. The author also developed for and took part in numerous software demonstrations, where user feedback was also collected. This included suggestions for practical use of the HMDs and responses to comfort and immersion when using the demonstrations. In Chapter 2, academic studies were designed to test assumptions and explore some of the ideas generated from the preliminary work. The collection of data had a heavy emphasis on qualitative feedback. This served to guide the development of new applications as well as the author's research. Much of this feedback pertained to user experience of the HMD, vection and movement in the virtual environment, and the design of the task itself. More specifically, the majority of quotes related to the comfort of the experience, as well as comments on realism, UI design and control interface.

This feedback, combined with the development of more a complex VR training application led to the formation of a new research direction. It was found that VR sickness was a significant contributing factor in the failure of the study design. Utilising newer consumer HMDs with wider FOVs (110 degrees) began to exacerbate this problem. It was the informed conclusion of the author that a universal platform-agnostic method for combating VR sickness would be a valuable tool for VR development across industry. In Chapter 3, this motivation is introduced through a couple of proposed methods. The first was a method for switching the camera from first-person to a third-person perspective, primarily during transitional animation sequences. The other was Dynamic FOV (DFOV) constriction, where the field of view would be reduced as the result of character movements, depending on the velocity of the movement. The reduction of FOV had been shown to reduce VR sickness, however, it also became a factor in the reduction of immersion. The author theorised that reducing FOV only when necessary, and in a subtle way would help to retain a high sense of presence.

Chapter 4 details the first study attempting to implement a suitable DFOV constriction system. To the author's knowledge at, the time there were no other studies attempting this (Fernandes & Feiner's study [1] was not published until 6 months after the author's). The proposed method was to utilise a vignetting script packaged with the Unity game engine, which would simulate a tunnel-vision effect. This was seen as a subtle and smooth way of transitioning between FOVs. In this study, manipulation of FOV was based on the character's translational velocity head movements and angular/rotational velocity of the character was not included. Participants were asked to navigate around an engine room using the Oculus Rift and Xbox controller. They were asked to follow a path and to rotate a certain number of valves. This was designed to encourage the user to walk different speeds and turn a lot. Turning of the valves included a transitional animation, where the FOV would reduce to help mitigate a sickening effect as the result of taking control of the camera. There were 5 conditions, where each participant would do trials each; one where there was no DFOV constriction, and a second trial using one of four DFOV settings. These were a combination of two factors: speed of constriction (fast vs slow), and maximum FOV reduction (narrow vs wide). The results showed no significant differences in VR sickness with or without the use of DFOV constriction. This was, however, more related to the design of the experiment and the experimental task as opposed to the effectiveness of DFOV. It was shown that the task was not engaging or sickness-inducing enough to yield an accurate evaluation of DFOV constriction.

A second study was therefore carried out, this time changing the virtual environment design and task. Many different ideas were generated for the method by which VR sickness should be tested. Further research on DFOV by this point had been published. Therefore, in an attempt to explore new avenues informed by the published results, the aim shifted to trying to further mitigate other causes of VR sickness using the

DFOV constriction method. The author felt there would be value in a developing a method which would allow developers to include more facets typically found in first-person applications such as head-bobbing, contextual involuntary animations on the character such as stumbling and falling and transitional animations.

For the final study outlined in Chapter 5 the author replicated and expanded on some of the methodology outlined in the research by Ferndades and Feiner [1]. The biggest change to the implementation of the author's DFOV constriction calculation was modelled on the method in their research. The new DFOV algorithm now took rotational velocity into account. The implementation of DFOV was still done using the author's technique, as it was of the author's opinion that it was easier to conceptualise the levels of FOV change than the method in Fernades and Feiners work. Similar parameters for DFOV constriction were adopted according to the result of their paper as it was shown to significantly reduced VR sickness while the participant travelled around the VE with a game controller. Other adoptions included the method for measuring and analysing the user's state of discomfort by making use of the Discomfort Score [61]. The results from the author's final study showed that although the DFOV constriction did not make an impact on sense of presence, it also did not significantly help to reduce VR sickness. There are a number of factors discussed in Section 5.7 as to why DFOV constriction did not help, main issues being that DFOV sometimes proved distracting and/or for the participants, and the lack of personal customisation of settings.

To date, there have not been any further studies to the author's knowledge of dynamic FOV constriction being used as a means of mitigating VR sickness. However, more recent approaches have included amplified head rotations. The study by Ragan et al (2017) [64] amplified head rotations to varying degrees depending on the experimental condition. This was done by a linear cumulative increase in simulated head turn. For example, if the user turned their head 30 degrees, the virtual camera would be turned 40 degrees, and a user at 45 degrees would mean the virtual camera was at 60 degrees. Not only was the aim to reduce fatigue and physical burden of users in a static set up, it was also to reduce VR sickness while maintaining presence. This method was tested on both CAVE and immersive HMD system and was found that increased amplification in HMD conditions did not mitigate VR sickness during tasks.

Another study has looked at guided and amplified head rotation [65]. Guided rotation used a similar method to amplify head rotation, except it also involves a method for re-aligning the orientation of the virtual camera. For this study they took gaming experience into account. They found that amplified head rotation on VR sickness was lower for participants who had experience in gaming than those with less experience.

Many approaches to combating VR sickness require body sensations to be somewhat synchronised with what is being presented visually. Some approaches have included rotating chairs and upper-body haptic feedback. One poster in this year's conference proposed using consumer air cushions to work in conjunction with vection in the virtual world [66]. Participants were given a cushion to sit on, as well as two long cushion strips on the back-rest, which would expand or contract depending on the movement in-session. The applications used were either a virtual ship or a virtual roller coaster. The results showed that using both types of cushion in conjunction helped to reduce VR sickness.

6.2 Contribution

Consumer VR has begun to enter into the mainstream in both gaming and industry. Some of the most popular systems allow users to move freely in a confined space. However, for needs and applications, a static vection method is still required, where the user is sat or is in a stationary position while operating the HMD. There are use cases in projects undertaken by the sponsor company which would require a portable (seated) VR solution. The author aimed to provide a universal screen-based method for mitigating VR sickness while allowing immersion to be maintained. This involved dynamically changing the field-of-view in response to player movement and virtual body rotation in order to reduce optical flow in the peripheral visual field, and therefore reduce VR sickness. The author also attempted to break some of the established rules of VR design by implementing involuntary camera movements via stumbling on a ship, in order to further test whether the DFOV method would be effective.

VR sickness to this date (2017) is still a primary concern for VR developers. Since the study in Chapter 5, VR gaming has become more mainstream with consumer releases for HTC Vive, Oculus Rift, PlayStation VR, Google Daydream and Samsung Galaxy Gear to name a few. As of now, vection in VR is still a barrier to the experience of the user. Full triple-A (high production value) games have been released such as Farpoint and Resident Evil 7, which rely on conventional methods of travel, where rotating the whole body is done in approximately 30-degree increments rather than the smooth movement attempted by the author.

The study outlined in Chapter 2, while suffering from an underpowered sample size, did reveal some of the challenges in developing consumer VR applications, in particular applications for pan-defence training. VR sickness stood out as an important challenge to overcome.

Although the proposed method for Dynamic FOV constriction did not ultimately prove to reliably reduce VR sickness, the work in this thesis will help to shape future research about such a method. Studies by Bolas [58] and Fernandez & Feiner [1] have shown that this is possible with normal locomotion in VR. This research aimed to further extend this method to be more reactive to a wider range of camera and character movements. The author believes the methodology devised for testing is also a contribution to research in this field and will provide the groundwork for future studies. To elaborate, causing DFOV constriction to be responsive to transitional animations and involuntary movements provides an interesting test case for such a method. An emphasis on active searching and locomotion in the study design may help to further refine this method.

A novel analysis was developed for analysing discomfort scores by looking at the average (weighted) progression of discomfort between recordings (see Section 5.6.1 for 'Average Discomfort Score' analysis). An analytic pipeline was developed incorporating SSQ scores which were analysed both in raw form and relative form (change over time). This method can be extended and utilised in future studies.

The design to elicit VR sickness was a novel method developed by the author. Using the medium of stumbling was an ideal action to implement as it involved involuntary vection, transitional animations and head-bobbing. It also reflected a realistic reaction to moving on a tilting surface, which would add to the realism. The setting was also a novel approach to the usual open-environment design. While the user was in an outdoor setting, they were restricted in movement but the bounds of the deck of the ship, while also having to navigate walls and other obstacles. Giving the participant an easy access to the sea and horizon further allows them to orient themselves and reduce VR sickness in a more naturalistic way, reducing the number of factors contributing overall to sickness induction.

This is the first study attempting to elicit VR sickness by methods which are not recommended in VR design, in an attempt to further develop the DFOV constriction method. The implementation was also done differently: where other methods interpolated between a series of images, this study used a real-time vignetting approach which provided a lot more opportunity for customisation and fine-tuning. It presents a more user-friendly way of categorising and configuring different levels of constriction and reaction depending on the users' needs.

Chapter 5 is considered an amalgamation of all of the author's prior research and many of the suggestions for future work are outlined in Section 5.7. While the results showed that DFOV constriction did not help with VR sickness during involuntary animations and movements, a number of variations for future experimentation were identified which would suggest DFOV constriction cannot be ruled out yet. With more research the author believes DFOV constriction will prove to be a viable tool for future VR implementation.

References

[1] A. S. Fernandes and S. K. Feiner, "Combating vr sickness through subtle dynamic field-of-view modification," in *2016 IEEE Symposium on 3D User Interfaces (3DUI)*, pp. 201–210, March 2016.

[2] Oculus, "Health and safety online brief."

[3] J. Popa, "Oculus rift: Dk1 vs dk2."

[4] R. Info, "Oculus rift specs dk1 vs dk2 comparison."

[5] G. Llorach, A. Evans, and J. Blat, "Simulator sickness and presence using hmds: Comparing use of a game controller and a position estimation system," in *Proceedings of the 20th ACM Symposium on Virtual Reality Software and Technology*, VRST 14, (New York, NY, USA), pp. 137–140, ACM, 2014.

[6] F. Xiao, Y. Jin, Y. Yin, and Y. Li, "Design and research of marine search and rescue simulation system," in *Proceedings of the 2010 Second International Conference on Information Technology and Computer Science*, ITCS '10, (Washington, DC, USA), pp. 372–376, IEEE Computer Society, 2010.

[7] P. Howarth and P. Costello, "The occurrence of virtual simulation sickness symptoms when an hmd was used as a personal viewing system," *Displays*, vol. 18, no. 2, pp. 107 – 116, 1997.

[8] T. Shibata, J. Kim, D. M. Hoffman, and M. S. Banks, "The zone of comfort: Predicting visual discomfort with stereo displays," *Journal of Vision*, vol. 11, no. 8, p. 11, 2011.

[9] J. E. Bos, W. Bles, and E. L. Groen, "A theory on visually induced motion sickness," *Displays*, vol. 29, no. 2, pp. 47 – 57, 2008. Health and Safety Aspects of Visual Displays.

[10] R. S. Kennedy, J. Drexler, and R. C. Kennedy, "Research in visually induced motion sickness," *Applied Ergonomics*, vol. 41, no. 4, pp. 494 – 503, 2010. Special Section - The First International Symposium on Visually Induced Motion Sickness, Fatigue, and Photosensitive Epileptic Seizures.

[11] L. J. Smart, T. A. Stoffregen, and B. G. Bardy, "Visually induced motion sickness predicted by postural instability," *Human Factors: The Journal of the Human Factors and Ergonomics Society*, vol. 44, no. 3, pp. 451–465, 2002.

[12] J. J. LaViola, Jr., "A discussion of cybersickness in virtual environments," *SIGCHI Bull.*, vol. 32, pp. 47–56, Jan. 2000.

[13] J. D. Moss and E. R. Muth, "Characteristics of head-mounted displays and their effects on simulator sickness.," *Human Factors*, vol. 53, no. 3, pp. 308–319, 2011.

[14] R. Stone, "Human factors guidelines for interactive 3d and games-based training systems design," 2008.

[15] R. J. Stone, "Human factors guidance for designers of interactive 3d and games-based training systems," 2012.

[16] C. Best, G. Galanis, J. Kerry, and R. Sottilare, *Fundamental Issues in Defense Training and Simulation.* Ashgate Publishing Company, 2013.

[17] C. M. Covas-Smith, R. E. Patterson, C. L. Kunkle, and L. M. Tripp, "Effects of level of model control for implicit learning of decision support systems," in *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, vol. 57, pp. 1585–1589, SAGE Publications, 2013.

[18] E. Ragan, D. Bowman, and K. Huber, "Supporting cognitive processing with spatial information presentations in virtual environments," *Virtual Reality*, vol. 16, no. 4, pp. 301–314, 2012.

[19] R. E. Patterson, B. J. Pierce, A. S. Boydstun, L. M. Ramsey, J. Shannan, L. Tripp, and H. Bell, "Training intuitive decision making in a simulated real-world environment," *Human Factors: The Journal of the Human Factors and Ergonomics Society*, p. 0018720812454432, 2012.

[20] B. G. Witmer and M. J. Singer, "Measuring presence in virtual environments: A presence questionnaire," *Presence: Teleoperators and virtual environments*, vol. 7, no. 3, pp. 225–240, 1998.

[21] M. Slater, M. Usoh, and A. Steed, "Depth of presence in virtual environments," *Presence: Teleoper. Virtual Environ.*, vol. 3, pp. 130–144, Jan. 1994.

[22] M. Usoh, E. Catena, S. Arman, and M. Slater, "Using presence questionnaires in reality," *Presence*, vol. 9, no. 5, pp. 497–503, 2000.

[23] A. Spagnolli, C. Bracken, and V. Orso, "The role played by the concept of presence in validating the efficacy of a cybertherapy treatment: a literature review," *Virtual Reality*, vol. 18, no. 1, pp. 13–36, 2014.

[24] J. Gibson, *The ecological approach to visual perception.* Houghton Mifflin, 1979.

[25] T. Regia-Corte, M. Marchal, G. Cirio, and A. Lcuyer, "Perceiving affordances in virtual reality: influence of person and environmental properties in perception of standing on virtual grounds," *Virtual Reality*, vol. 17, no. 1, pp. 17–28, 2013.

[26] V. Braun and V. Clarke, "Using thematic analysis in psychology," *Qualitative research in psychology*, vol. 3, no. 2, pp. 77–101, 2006.

[27] H. Cooper, P. M. Camic, D. L. Long, A. T. Panter, D. Rindskopf, and K. J. Sher, *APA handbook of research methods in psychology, Vol 2: Research designs: Quantitative, qualitative, neuropsychological, and biological.*

[28] A. Field, *Discovering Statistics Using SPSS.* SAGE Publications, 2005.

[29] B. Keshavarz, B. Riecke, L. Hettinger, and J. Campos, "Vection and visually induced motion sickness: How are they related?," vol. 6, p. 472, 04 2015.

[30] Z. Popović and A. Witkin, "Physically based motion transformation," in *Proceedings of the 26th Annual Conference on Computer Graphics and Interactive Techniques*, SIGGRAPH '99, (New York, NY, USA), pp. 11–20, ACM Press/Addison-Wesley Publishing Co., 1999.

[31] OculusVR, "Oculus best practices."

[32] "http://www.chioka.in/what-is-motion-to-photon-latency/."

[33] S. Kawamura and R. Kijima, "Effect of hmd latency on human stability during quiescent standing on one foot," in *2016 IEEE Symposium on 3D User Interfaces (3DUI)*, pp. 141–144, March 2016.

[34] M. H. Draper, E. S. Viirre, T. A. Furness, and V. J. Gawron, "Effects of image scale and system time delay on simulator sickness within head-coupled virtual environments," *Human Factors: The Journal of the Human Factors and Ergonomics Society*, vol. 43, no. 1, pp. 129–146, 2001.

[35] R. Kijima and K. Miyajima, "Measurement of head mounted display's latency in rotation and side effect caused by lag compensation by simultaneous observation; an example result using oculus rift dk2," in *2016 IEEE Virtual Reality (VR)*, pp. 203–204, March 2016.

[36] K. Mania, B. D. Adelstein, S. R. Ellis, and M. I. Hill, "Perceptual sensitivity to head tracking latency in virtual environments with varying degrees of scene complexity," in *Proceedings of the 1st Symposium on Applied Perception in Graphics and Visualization*, APGV '04, (New York, NY, USA), pp. 39–47, ACM, 2004.

[37] R. S. Kennedy, N. E. Lane, K. S. Berbaum, and M. G. Lilienthal, "Simulator sickness questionnaire: An enhanced method for quantifying simulator sickness," *The international journal of aviation psychology*, vol. 3, no. 3, pp. 203–220, 1993.

[38] S. L. Ames, J. S. Wolffsohn, and N. A. Mcbrien, "The development of a symptom questionnaire for assessing virtual reality viewing using a head-mounted display," *Optometry & Vision Science*, vol. 82, no. 3, pp. 168–176, 2005.

[39] B. Keshavarz and H. Hecht, "Validating an efficient method to quantify motion sickness," *Human Factors: The Journal of the Human Factors and Ergonomics Society*, vol. 53, no. 4, pp. 415–426, 2011.

[40] J. E. Bos, S. C. de Vries, M. L. van Emmerik, and E. L. Groen, "The effect of internal and external fields of view on visually induced motion sickness," *Applied Ergonomics*, vol. 41, no. 4, pp. 516 – 521, 2010. Special Section - The First International Symposium on Visually Induced Motion Sickness, Fatigue, and Photosensitive Epileptic Seizures.

[41] B. Riecke, "Compelling self-motion through virtual environments without actual self-motion: using self-motion illusions (vection) to improve user experience in vr," *Virtual reality*, pp. 149–176, 2011.

[42] W. Bles and A. H. Wertheim, "Appropriate use of virtual environments to minimise motion sickness," tech. rep., DTIC Document, 2001.

[43] F. Rebelo, P. Noriega, E. Duarte, and M. Soares, "Using virtual reality to assess user experience," *Human Factors: The Journal of the Human Factors and Ergonomics Society*, p. 0018720812465006, 2012.

[44] X. Luo, R. Kenyon, D. Kamper, D. Sandin, and T. DeFanti, "The effects of scene complexity, stereovision, and motion parallax on size constancy in a virtual environment," in *2007 IEEE Virtual Reality Conference*, pp. 59–66, March 2007.

[45] E. D. Ragan, D. A. Bowman, R. Kopper, C. Stinson, S. Scerbo, and R. P. McMahan, "Effects of field of view and visual complexity on virtual reality training effectiveness for a visual scanning task," *IEEE Transactions on Visualization and Computer Graphics*, vol. 21, pp. 794–807, July 2015.

[46] T. Sharkey and M. McCauley, "Does a motion base prevent simulator sickness?," 02 1992.

[47] C. Diels, K. Ukai, and P. A. Howarth, "Visually induced motion sickness with radial displays: effects of gaze angle and fixation.," *Aviation, space, and environmental medicine*, vol. 78 7, pp. 659–65, 2007.

[48] A. Bubka, F. Bonato, and S. Palmisano, "Expanding and contracting optic-flow patterns and vection," *Perception*, vol. 37, no. 5, pp. 704–711, 2008. PMID: 18605144.

[49] L. J. S. Jr., E. W. Otten, A. J. Strang, E. M. Littman, and H. E. Cook, "Influence of complexity and coupling of optic flow on visually induced motion sickness," *Ecological Psychology*, vol. 26, no. 4, pp. 301–324, 2014.

[50] A. M. Gavgani, D. M. Hodgson, and E. Nalivaiko, "Effects of visual flow direction on signs and symptoms of cybersickness," in *PloS one*, 2017.

[51] J.-W. Lin, H. Duh, D. Parker, H. Abi-Rached, and T. Furness, "Effects of field of view on presence, enjoyment, memory, and simulator sickness in a virtual environment," in *Virtual Reality, 2002. Proceedings. IEEE*, pp. 164–171, 2002.

[52] P. Sparto, S. Whitney, L. Hodges, J. Furman, and M. Redfern, "Simulator sickness when performing gaze shifts within a wide field of view optic flow environment: preliminary evidence for using virtual reality in vestibular rehabilitation," *Journal of NeuroEngineering and Rehabilitation*, vol. 1, no. 1, p. 14, 2004.

[53] A. F. Seay, D. M. Krum, L. Hodges, and W. Ribarsky, "Simulator sickness and presence in a high fov virtual environment," in *Virtual Reality, 2001. Proceedings. IEEE*, pp. 299–300, March 2001.

[54] Y. Y. Kim, E. N. Kim, M. J. Park, K. S. Park, H. D. Ko, and H. T. Kim, "The application of biosignal feedback for reducing cybersickness from exposure to a virtual environment," *Presence*, vol. 17, pp. 1–16, Feb 2008.

[55] F. Steinicke and G. Bruder, "A self-experimentation report about long-term use of fully-immersive technology," in *Proceedings of the 2Nd ACM Symposium on Spatial User Interaction*, SUI '14, (New York, NY, USA), pp. 66–69, ACM, 2014.

[56] R. S. Kennedy, K. M. Stanney, and W. P. Dunlap, "Duration and exposure to virtual environments: Sickness curves during and across sessions," *Presence: Teleoperators and Virtual Environments*, vol. 9, no. 5, pp. 463–472, 2000.

[57] "Running from the reality: Vr treadmills."

[58] M. Bolas, J. Jones, I. McDowall, and E. Suma, "Dynamic field of view throttling as a means of improving user experience in head mounted virtual environments," 2014. US Patent App. 14/216,220.

[59] J. J. W. Lin, H. Abi-Rached, and M. Lahav, "Virtual guiding avatar: An effective procedure to reduce simulator sickness in virtual environments," in *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, CHI '04, (New York, NY, USA), pp. 719–726, ACM, 2004.

[60] Unity, "Vignetting and chromatic aberration documentation." https://docs.unity3d.com/Manual/script-VignettingAndChromaticAberration.html.

[61] L. Rebenitsch and C. Owen, "Individual variation in susceptibility to cybersickness," in *Proceedings of the 27th Annual ACM Symposium on User Interface Software and Technology*, UIST '14, (New York, NY, USA), pp. 309–317, ACM, 2014.

[62] G. Robillard, S. Bouchard, T. Fournier, and P. Renaud, "Anxiety and presence during vr immersion: A comparative study of the reactions of phobic and non-phobic participants in therapeutic virtual environments derived from computer games," *CyberPsychology & Behavior*, vol. 6, no. 5, pp. 467–476, 2003.

[63] J. Cohen, *Statistical power analysis for the behavioral sciences.*

[64] E. D. Ragan, S. Scerbo, F. Bacim, and D. A. Bowman, "Amplified head rotation in virtual reality and the effects on 3d search, training transfer, and spatial orientation," *IEEE Transactions on Visualization and Computer Graphics*, vol. PP, no. 99, pp. 1–1, 2016.

[65] S. P. Sargunam, K. R. Moghadam, M. Suhail, and E. D. Ragan, "Guided head rotation and amplified head rotation: Evaluating semi-natural travel and viewing techniques in virtual reality," in *2017 IEEE Virtual Reality (VR)*, pp. 19–28, March 2017.

[66] Y. Onuki, S. Ono, and I. Kumazawa, "Air cushion: A pilot study of the passive technique to mitigate simulator sickness by responding to vection," in *2017 IEEE Virtual Reality (VR)*, pp. 323–324, March 2017.

Appendix A

Study Design for Determining Effectiveness of Immersive HMD

Experience Questionnaire ………………………………

Gaming Experience

1. Do you play video games very often?

Please circle one option

1 – *Not at all*	**2**	**3** - *Occasionally*	**4**	**5** - *Regularly*

2. If you play/ have played video games, do you have experience with console game controllers (e.g. Xbox or Playstation Controllers)?

Please circle one option

1 – *Not at all*	**2**	**3** – *Some experience*	**4**	**5** – *A lot of experience*

3. If you play/ have played video games, do you play First-Person-Perspective games?

Please circle one option

1 – *Not at all*	**2**	**3** - *Occasionally*	**4**	**5** - *Regularly*

Virtual Experience

4. Have you used or have experience in virtual training?

Please circle one option

1 – *Not at all*	**2** - *Occasionally*	**3** –*Some Experience*	**4** –*Regular Experience*	**5** – *Subject-Matter Expert*

5. Do you/ have you used head-mounted displays (HMDs)?

Please circle one option

1 – *Not at all*	**2** – *Very few times*	**3** –*Some times*	**4** –*Regularly*	**5** – *Subject-Matter Expert*

6. Do you/ have you used the Oculus Rift (Development Kit 1 or 2)?

Please circle one option

1 – *Not at all*	**2** – *Very few times*	**3** –*Some times*	**4** –*Regularly*	**5** – *Subject-Matter Expert*

7. Do you experience Motion Sickness?

Please circle one option

1 – *Not at all*	**2**	**3**–*A little*	**4**	**5** – *A lot*

8. Have you experienced discomfort or motion sickness as a result or using HMDs?

Please circle one option

1 – *Not Applicable*	**2** – *Not at all*	**3** –*A little*	**4** –*After prolonged use*	**5** – *Immediately*

Maritime Experience

9. Do you have any maritime experience (Naval or otherwise?)

Please circle one option

1 – *Not at all*	**2** - *Occasionally*	**3** –*Some Experience*	**4** –*Regular Experience*	**5** – *Subject-Matter Expert*

10. How many years of naval experience do you have?

Please circle one option

1 – *Not Applicable*	**2** – *0-1 year*	**3** –*1-5 Years*	**4** –*6 -19 Years*	**5** – *20+ years*

11. Are you familiar with the procedures of Replenishment at Sea/ Underway Replenishment?

Please circle one option

1 – *Not at all*	**2** – *Overview*	**3** –*Detailed knowledge*	**4** –*In-service training*	**5** – *Have been involved in one*

Presence Questionnaire

1. How much were you able to control events?

1	2	3	4	5	6	7
NOT AT ALL			SOMEWHAT			COMPLETELY

2. How responsive was the environment to actions that you initiated (or performed)?

1	2	3	4	5	6	7
NOT RESPONSIVE			MODERATELY RESPONSIVE			COMPLETELY RESPONSIVE

3. How natural did your interactions with the environment seem?

1	2	3	4	5	6	7
EXTREMELY ARTIFICIAL			BORDERLINE			COMPLETELY NATURAL

4. How completely were *all* of your senses engaged?

1	2	3	4	5	6	7
NOT AT ALL			SOMEWHAT			COMPLETELY

5. How much did the visual aspects of the environment involve you?

1	2	3	4	5	6	7
NOT AT ALL			SOMEWHAT			COMPLETELY

6. How much did the auditory aspects of the environment involve you?

1	2	3	4	5	6	7
NOT AT ALL			SOMEWHAT			COMPLETELY

7. How natural was the mechanism which controlled movement through the environment?

1	2	3	4	5	6	7
EXTREMELY ARTIFICIAL			BORDERLINE			COMPLETELY NATURAL

8. How aware were you of events occurring in the real world around you?

1	2	3	4	5	6	7
COMPLETELY UNAWARE			SOMEWHATAWARE			COMPLETELY AWARE

9. How aware were you of your display and control devices?

1	2	3	4	5	6	7
COMPLETELY UNAWARE			SOMEWHAT AWARE			COMPLETELY AWARE

10. How compelling was your sense of objects moving through space?

1	2	3	4	5	6	7
NOT COMPELLING			MODERATELY COMPELLING			VERY COMPELLING

11. How inconsistent or disconnected was the information coming from your various senses?

1	2	3	4	5	6	7
VERY INCONSISTENT			BORDERLINE			VERY COCSISTENT

12. How much did your experiences in the virtual environment seem consistent with your real-world experiences?

1	2	3	4	5	6	7
VERY INCONSISTENT			**BORDERLINE**			**VERY COCSISTENT**

13. Were you able to anticipate what would happen next in response to the actions that you performed?

1	2	3	4	5	6	7
NOT AT ALL			**SOMEWHAT**			**COMPLETELY**

14. How completely were you able to actively survey or search the environment using vision?

1	2	3	4	5	6	7
NOT AT ALL			**SOMEWHAT**			**COMPLETELY**

15. How well could you identify sounds?

1	2	3	4	5	6	7
NOT AT ALL			**SOMEWHAT**			**COMPLETELY**

16. How well could you localize sounds?

1	2	3	4	5	6	7
NOT AT ALL			**SOMEWHAT**			**COMPLETELY**

17. How well could you actively survey or search the virtual environment using touch?

1	2	3	4	5	6	7
NOT AT ALL			**SOMEWHAT**			**COMPLETELY**

18. How compelling was your sense of moving around inside the virtual environment?

1	2	3	4	5	6	7
NOT AT ALL			**MODERATELY COMPELLING**			**VERY COMPELLING**

19. How closely were you able to examine objects?

1	2	3	4	5	6	7
NOT AT ALL			**PRETTY CLOSELY**			**VERY CLOSELY**

20. How well could you examine objects from multiple viewpoints?

1	2	3	4	5	6	7
NOT AT ALL			**SOMEWHAT**			**COMPLETELY**

21. How well could you move or manipulate objects in the virtual environment?

1	2	3	4	5	6	7
NOT AT ALL			**SOMEWHAT**			**COMPLETELY**

22. To what degree did you feel confused or disoriented at the beginning of breaks or at the end of the experimental session?

1	2	3	4	5	6	7
NOT AT ALL			**SOMEWHAT ILL**			**VERY ILL**

23. How involved were you in the virtual environment experience?

1	2	3	4	5	6	7
NOT AT ALL			SOMEWHAT INVOLVED		COMPLETELY INVOLVED	

24. How distracting was the control mechanism?

1	2	3	4	5	6	7
NOT AT ALL			SOMEWHAT DISTRACTING			VERY DISTRACTING

25. How much delay did you experience between your actions and expected outcomes?

1	2	3	4	5	6	7
NO DELAYS			MODERATE DELAYS			LONG DELAYS

26. How quickly did you adjust to the virtual environment experience?

1	2	3	4	5	6	7
NO AT ALL			SLOWLY			IMMEDIATELY

27. How proficient in moving and interacting with the virtual environment did you feel at the end of the experience?

1	2	3	4	5	6	7
NOT PROFICIENT			REASONABLY PROFICIENT			VERY PROFICIENT

28. How much did the visual display quality interfere or distract you from performing assigned tasks or required activities?

1	2	3	4	5	6	7
NOT AT ALL			INTEFERED			PREVENTED TASK PERFORMANCE

29. How much did the control devices interfere with the performance of assigned tasks or with other activities?

1	2	3	4	5	6	7
NOT AT ALL			INTEFERED SOMEWHAT			INTEFERED GREATLY

30. How well could you concentrate on the assigned tasks or required activities rather than on the mechanisms used to perform those tasks or activities?

1	2	3	4	5	6	7
NOT AT ALL			SOMEWHAT			COMPLETELY

31. Did you learn new techniques that enabled you to improve your performance?

1	2	3	4	5	6	7
NOT AT ALL			SOMEWHAT			A GREAT AMOUNT

32. Were you involved in the experimental task to the extent that you lost track of time?

1	2	3	4	5	6	7
NOT AT ALL			SOMEWHAT			COMPLETELY

Immersive Tendencies Questionnaire

1. Do you ever get extremely involved in projects that are assigned to you by your boss or your instructor, to the exclusion of other tasks?

1	**2**	**3**	**4**	**5**	**6**	**7**
NOT AT ALL			**OCCASIONALLY**			**OFTEN**

2. How easily can you switch your attention from the task in which you are currently involved to a new task?

1	**2**	**3**	**4**	**5**	**6**	**7**
NOT AT ALL			**SOMEWHAT**			**VERY EASILY**

3. How frequently do you get emotionally involved (angry, sad, or happy) in the news stories that you read or hear?

1	**2**	**3**	**4**	**5**	**6**	**7**
NOT AT ALL			**OCCASIONALLY**			**OFTEN**

4. How well do you feel today?

1	**2**	**3**	**4**	**5**	**6**	**7**
NOT WELL			**MODERATELY WELL**			**VERY WELL**

5. Do you easily become deeply involved in movies or TV dramas?

1	**2**	**3**	**4**	**5**	**6**	**7**
NOT WELL			**SOMEWHAT**			**VERY EASILY**

6. Do you ever become so involved in a television program or book that people have problems getting your attention?

1	**2**	**3**	**4**	**5**	**6**	**7**
NOT AT ALL			**OCCASIONALLY**			**OFTEN**

7. How mentally alert do you feel at the present time?

1	**2**	**3**	**4**	**5**	**6**	**7**
NOT VERY ALERT			**SOMEWHAT ALERT**			**VERY ALERT**

8. Do you ever become so involved in a movie that you are not aware of things happening around you?

1	**2**	**3**	**4**	**5**	**6**	**7**
NOT AT ALL			**OCCASIONALLY**			**OFTEN**

9. How frequently do you find yourself closely identifying with the characters in a story line?

1	**2**	**3**	**4**	**5**	**6**	**7**
NOT AT ALL			**OCCASIONALLY**			**OFTEN**

10. Do you ever become so involved in a video game that it is as if you are inside the game rather than moving a joystick and watching the screen?

1	**2**	**3**	**4**	**5**	**6**	**7**
NOT AT ALL			**OCCASIONALLY**			**OFTEN**

11. On average, how many books do you read for enjoyment in a month?

1	2	3	4	5	6	7
NONE			**1 OR 2**			**MORE THAN 2**

12. What kind of books do you read most frequently? —(CIRCLE ONE ITEM ONLY!)

Spy novels	***Fantasies***	***Science fiction***	***Adventure***
Romance novels	***Historical novels***	***Westerns***	***Mysteries***
Other fiction	***Biographies***	***Autobiographies***	***Other non-fiction***

13. How physically fit do you feel today?

1	2	3	4	5	6	7
NOT AT ALL			**MODERATELY FIT**			**VERY FIT**

14. How good are you at blocking out external distractions when you are involved in something?

1	2	3	4	5	6	7
NOT GOOD			**MODERATELY GOOD**			**VERY GOOD**

15. When watching sports, do you ever become so involved in the game that you react as if you were one of the players?

1	2	3	4	5	6	7
NOT AT ALL			**OCCASIONALLY**			**OFTEN**

16. Do you ever become so involved in a daydream that you are not aware of things happening around you?

1	2	3	4	5	6	7
NOT AT ALL			**OCCASIONALLY**			**OFTEN**

17. Do you ever have dreams that are so real that you feel disoriented when you wake?

1	2	3	4	5	6	7
NOT AT ALL			**OCCASIONALLY**			**OFTEN**

18. When playing sports, do you become so involved in the game that you lose track of time?

1	2	3	4	5	6	7
NOT AT ALL			**OCCASIONALLY**			**OFTEN**

19. Are you easily disturbed when working on a task?

1	2	3	4	5	6	7
NOT AT ALL			**SOMEWHAT**			**VERY EASILY**

20. How well do you concentrate on enjoyable activities?

1	2	3	4	5	6	7
NOT WELL			**MODERATELY WELL**			**VERY WELL**

21. How often do you play video games? (OFTEN should be taken to mean every day or every two days, on average.)

1	2	3	4	5	6	7
NOT AT ALL			**OCCASIONALLY**			**OFTEN**

22. How well do you concentrate on disagreeable tasks?

1	2	3	4	5	6	7
NOT WELL			**MODERATELY WELL**			**VERY WELL**

23. Have you ever gotten excited during a chase or fight scene on TV or in the movies?

1	2	3	4	5	6	7
NOT AT ALL			**OCCASIONALLY**			**OFTEN**

24. To what extent have you dwelled on personal problems in the last 48 hours?

1	2	3	4	5	6	7
NOT AT ALL			**OCCASIONALLY**			**OFTEN**

25. Have you ever gotten scared by something happening on a TV show or in a movie?

1	2	3	4	5	6	7
NOT AT ALL			**OCCASIONALLY**			**OFTEN**

26. Have you ever remained apprehensive or fearful long after watching a scary movie?

1	2	3	4	5	6	7
NOT AT ALL			**OCCASIONALLY**			**OFTEN**

27. Do you ever avoid carnival or fairground rides because they are too scary?

1	2	3	4	5	6	7
NOT AT ALL			**OCCASIONALLY**			**OFTEN**

28. How frequently do you watch TV soap operas or docu-dramas?

1	2	3	4	5	6	7
NOT AT ALL			**OCCASIONALLY**			**OFTEN**

29. Do you ever become so involved in doing something that you lose all track of time?

1	2	3	4	5	6	7
NOT AT ALL			**OCCASIONALLY**			**OFTEN**

Appendix B

Dynamic FOV Constriction: A New Approach to Controlling HMD Simulator Sickness: Pilot Study

Experiment Brief ………………………………

Summary

You will be asked to participate in a study which will take approximately 25 minutes to complete. You will use a COTS head-mounted display called **Oculus Rift (OR)**. The purpose of this study is to test ways of effectively simulating motion in virtual reality applications for training. Please ask the supervisor if you would like more details. You will be asked to perform a number of small tasks in the virtual world, where you will be controlling a virtual avatar and interacting with the environment using **OR** and an **Xbox Game Controller**. Video recordings will be taken of each trial in order to assist with analysis. When the trial is over, you will be asked to complete two questionnaires relating to your experience. The results of the questionnaires and recordings of the virtual trials will be analysed and published. ***There is also a short questionnaire attached to this document which I would like you to fill in prior to the experiment.***

Disclaimer

Using the OR may result in feelings of sickness and nausea, and can result in symptoms related to motion sickness, subject to individual susceptibilities**. If you feel you are unable to participate and would like to withdraw from the study, you may do so at any time**. Should the supervisor feel the experiment should not be continued due to health concerns, the study will be terminated immediately. Your identity and data will remain anonymous, and no personal information will be recorded. Video recordings will be used for analysis and seen by the researchers only. Please ask the supervisor if you would like further details.

please tick the boxes and sign below to acknowledge the following:

- I have read and understood the task I am performing for this experiment
- I have read and understood the disclaimer
- The supervisor has clarified any questions I may have raised
- I agree to participate in this study, and am aware I can withdraw at any time

Participant signature: ………………………………………………………………………………………

Supervisor emails: hashimy@bmtdsl.co.uk

PLEASE COMPLETE THE QUESTIONNAIRE OVERLEAF <u>BEFORE</u> ATTENDING THE EXPERIMENT

1. Do you have experience with console game controllers (e.g. Xbox or Playstation Controllers)?

Please circle one option

1 – *Not at all*	**2**– *Some experience*	**3** – *A lot of experience*

2. Have you any experience in virtual training?

Please circle one option

1 – *Not at all*	**2**– *Some experience*	**3** – *A lot of experience*

3. Have you used the Oculus Rift (Development Kit 1 or 2) before?

Please circle one option

1 – *Not at all*	**2**– *Some experience*	**3** – *A lot of experience*

4. Do you experience Motion Sickness?

Please circle one option

1 – *Not at all*	**2**–*A little*	**3** – *A lot*

5. Have you experienced discomfort or motion sickness as a result or using head-mounted displays?

Please circle one option

1 – *Never used them*	**2** – *Not at all*	**3** –*A little after prolonged use*	**4** –*A little immediately*	**5** – *A lot Immediately*

Presence Questionnaire

1. How much were you able to control events?

1	2	3	4	5	6	7
NOT AT ALL			SOMEWHAT			COMPLETELY

2. How responsive was the environment to actions that you initiated (or performed)?

1	2	3	4	5	6	7
NOT RESPONSIVE			MODERATELY RESPONSIVE			COMPLETELY RESPONSIVE

3. How natural did your interactions with the environment seem?

1	2	3	4	5	6	7
EXTREMELY ARTIFICIAL			BORDERLINE			COMPLETELY NATURAL

4. How completely were *all* of your senses engaged?

1	2	3	4	5	6	7
NOT AT ALL			SOMEWHAT			COMPLETELY

5. How much did the visual aspects of the environment involve you?

1	2	3	4	5	6	7
NOT AT ALL			SOMEWHAT			COMPLETELY

6. How natural was the mechanism which controlled movement through the environment?

1	2	3	4	5	6	7
EXTREMELY ARTIFICIAL			BORDERLINE			COMPLETELY NATURAL

7. How aware were you of events occurring in the real world around you?

1	2	3	4	5	6	7
COMPLETELY UNAWARE			SOMEWHATAWARE			COMPLETELY AWARE

8. How aware were you of your display and control devices?

1	2	3	4	5	6	7
COMPLETELY UNAWARE			SOMEWHAT AWARE			COMPLETELY AWARE

9. How compelling was your sense of objects moving through space?

1	2	3	4	5	6	7
NOT COMPELLING			MODERATELY COMPELLING			VERY COMPELLING

10. How inconsistent or disconnected was the information coming from your various senses?

1	2	3	4	5	6	7
VERY INCONSISTENT			BORDERLINE			VERY COCSISTENT

11. How much did your experiences in the virtual environment seem consistent with your real-world experiences?

1	2	3	4	5	6	7
VERY INCONSISTENT			**BORDERLINE**			**VERY COCSISTENT**

12. Were you able to anticipate what would happen next in response to the actions that you performed?

1	2	3	4	5	6	7
NOT AT ALL			**SOMEWHAT**			**COMPLETELY**

13. How completely were you able to actively survey or search the environment using vision?

1	2	3	4	5	6	7
NOT AT ALL			**SOMEWHAT**			**COMPLETELY**

14. How compelling was your sense of moving around inside the virtual environment?

1	2	3	4	5	6	7
NOT AT ALL			**MODERATELY COMPELLING**			**VERY COMPELLING**

15. How closely were you able to examine objects?

1	2	3	4	5	6	7
NOT AT ALL			**PRETTY CLOSELY**			**VERY CLOSELY**

16. How well could you examine objects from multiple viewpoints?

1	2	3	4	5	6	7
NOT AT ALL			**SOMEWHAT**			**COMPLETELY**

17. To what degree did you feel confused or disoriented at the beginning of breaks or at the end of the experimental session?

1	2	3	4	5	6	7
NOT AT ALL			**SOMEWHAT ILL**			**VERY ILL**

18. How involved were you in the virtual environment experience?

1	2	3	4	5	6	7
NOT AT ALL			**SOMEWHAT INVOLVED**			**COMPLETELY INVOLVED**

19. How distracting was the control mechanism?

1	2	3	4	5	6	7
NOT AT ALL			**SOMEWHAT DISTRACTING**			**VERY DISTRACTING**

20. How much delay did you experience between your actions and expected outcomes?

1	2	3	4	5	6	7
NO DELAYS			**MODERATE DELAYS**			**LONG DELAYS**

21. How quickly did you adjust to the virtual environment experience?

1	2	3	4	5	6	7
NO AT ALL			**SLOWLY**			**IMMEDIATELY**

22. How proficient in moving and interacting with the virtual environment did you feel at the end of the experience?

1	2	3	4	5	6	7
NOT PROFICIENT			**REASONABLY PROFICIENT**			**VERY PROFICIENT**

23. How much did the visual display quality interfere or distract you from performing assigned tasks or required activities?

1	2	3	4	5	6	7
NOT AT ALL			**INTEFERED**			**PREVENTED TASK PERFORMANCE**

24. How much did the control devices interfere with the performance of assigned tasks or with other activities?

1	2	3	4	5	6	7
NOT AT ALL			**INTEFERED SOMEWHAT**			**INTEFERED GREATLY**

25. How well could you concentrate on the assigned tasks or required activities rather than on the mechanisms used to perform those tasks or activities?

1	2	3	4	5	6	7
NOT AT ALL			**SOMEWHAT**			**COMPLETELY**

26. Did you learn new techniques that enabled you to improve your performance?

1	2	3	4	5	6	7
NOT AT ALL			**SOMEWHAT**			**A GREAT AMOUNT**

Participant:

1. General discomfort
2. Fatigue
3. Headache
4. Eye strain
5. Difficulty focusing
6. Salivation increasing
7. Sweating
8. Nausea
9. Difficulty concentrating
10. Fullness of the Head
11. Blurred vision
12. Dizziness with eyes open
13. Dizziness with eyes closed
14. *Vertigo
15. **Stomach awareness
16. Burping

* Vertigo is experienced as loss of orientation with respect to vertical upright.

** Stomach awareness is usually used to indicate a feeling of discomfort which is just short of nausea.

Appendix C

Main Study: Reducing VR Sickness using Dynamic FOV Convergence During Exaggerated Movements

Supervisor emails: Hashim Khalid Yaqub -- hky24@bath.ac.uk

Experiment Brief

Summary

You will be asked to participate in a study which will take approximately 25 minutes to complete. You will use a COTS head-mounted display called **Oculus Rift (OR)**. The purpose of this study is to test ways of effectively simulating motion in virtual reality applications for training. Please ask the supervisor if you would like more details. You will be asked to virtually walk around in the virtual world, where you will be controlling a virtual avatar and interacting with the environment using **OR** and an **Xbox Game Controller**. You will be asked to complete two questionnaires relating to your experience. The results of the questionnaires and recordings of the virtual trials will be analysed and published.

Task

The participant will be ask to walk around a virtual environment, moving from checkpoint to check-point. Every few checkpoints a question will appear. Using the arrow buttons on the controller, please select an answer.

Disclaimer

Using the OR may result in feelings of sickness and nausea, and can result in symptoms related to motion sickness, subject to individual susceptibilities**. If you feel you are unable to participate and would like to withdraw from the study, you may do so at any time**. Should the supervisor feel the experiment should not be continued due to health concerns, the study will be terminated immediately. Your identity and data will remain anonymous, and no personal information will be recorded. Please ask the supervisor if you would like further details.

please tick the boxes and sign below to acknowledge the following:

- ☐ I have read and understood the **task** I am performing for this experiment
- ☐ I have read and understood the **disclaimer**
- ☐ The supervisor has **clarified any questions** I may have raised
- ☐ I agree to **participate in this study**, and am aware **I can withdraw at any time**

If you would like to...

- ☐ ...be emailed with **debrief** and **result of study**...
- ☐ ...be entered into the prize draw for a **£100 voucher for Amazon**...

...please provide your email address:

...

Participant signature:

...

1. Do you have experience with console game controllers (e.g. Xbox or Playstation Controllers)?

Please circle one option

1 – *Not at all* **2**– *Some experience* **3** – *A lot of experience*

2. Have you used a Head-Mounted Display before?

Please circle one option

1 – *Not at all* **2**– *Some experience* **3** – *A lot of experience*

3. Do you experience Motion Sickness?

Please circle one option

1 – *Not at all* **2**–*A little* **3** – *A lot*

UNIVERSITY OF BATH

Department of Computer Science

Sit Back and Walk:
Movement in Virtual Reality

Would you like to be part of study looking to make Virtual Reality more comfortable.

You will use an Oculus Rift VR headset while walking around in virtual environment.

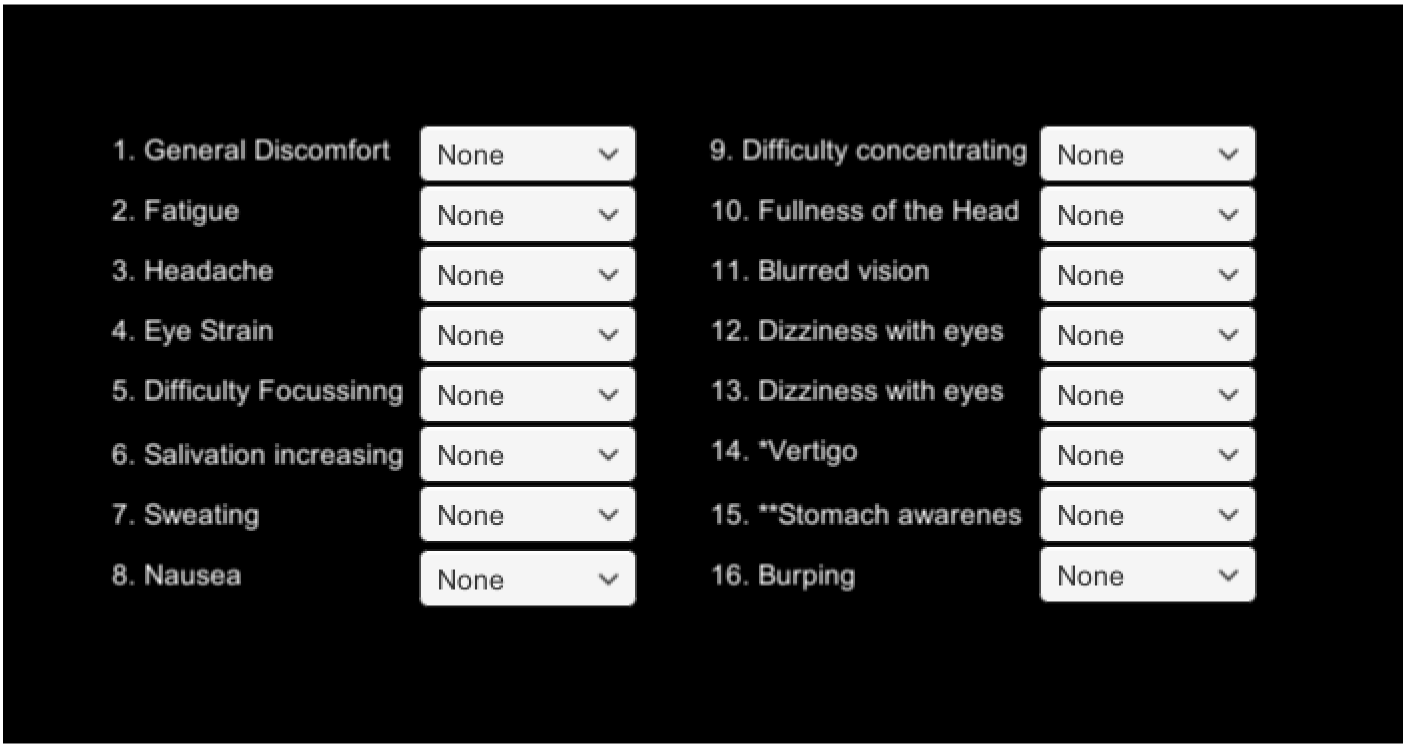
All are welcome, in particular those with little experience of VR headsets.

This study will take up to an hour of your time.

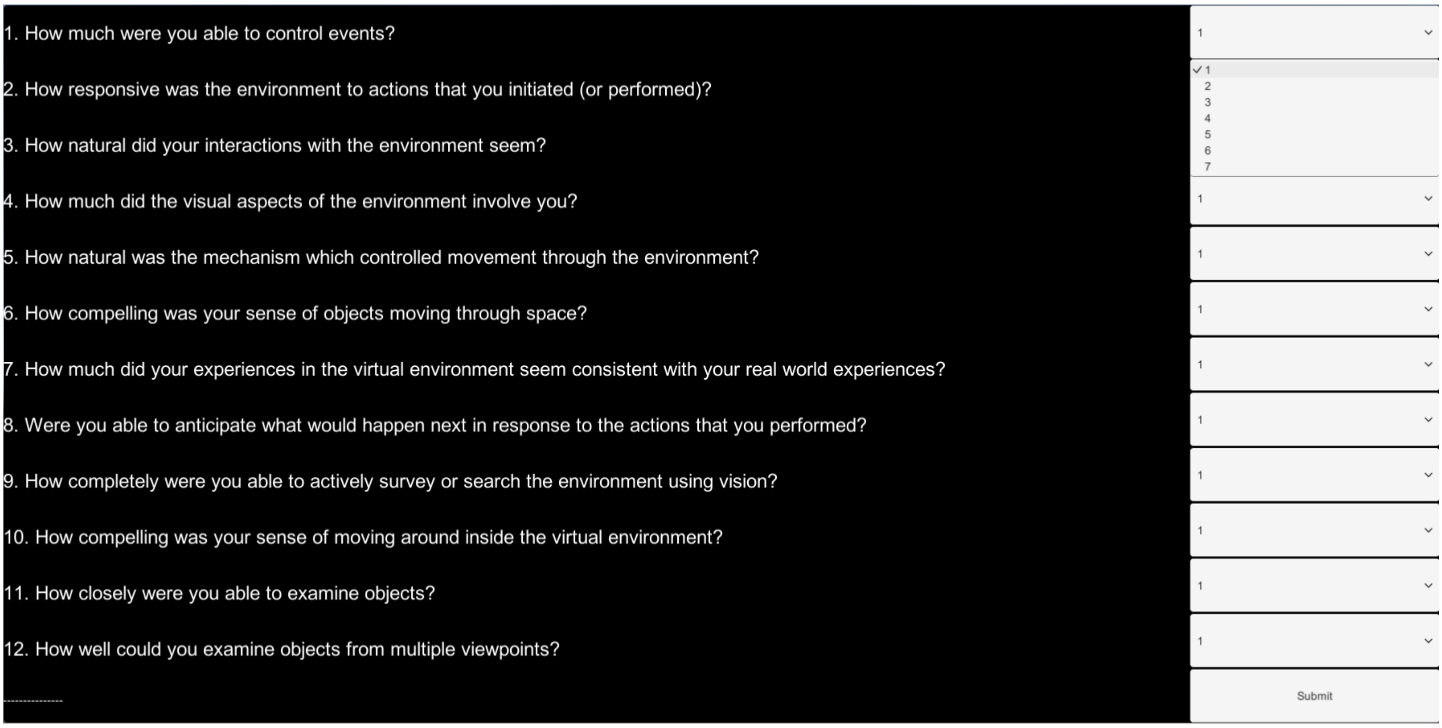
All participants will be entered into a prize draw for a chance to win a **£100 Amazon Voucher**.

To take part or find out more, contact **Hashim Yaqub** on hky24@bath.ac.uk. Please email with “**VR study**” in the subject line.

C.1 Simulator Sickness Unity Questionnaire



C.2 Presence Unity Questionnaire



13. How involved were you in the virtual environment experience?	1
14. How much delay did you experience between your actions and expected outcomes?	1
15. How quickly did you adjust to the virtual environment experience?	1
16. How proficient in moving and interacting with the virtual environment did you feel at the end of the experience?	1
17. How much did the visual display quality interfere or distract you from performing assigned tasks or required activities?	1
18. How much did the control devices interfere with the performance of assigned tasks or with other activities?	1
19. How well could you concentrate on the assigned tasks or required activities rather than on the mechanisms used to perform those tasks or activities?	1
20. How much did the auditory aspects of the environment involve you?	1
21. How well could you identify sounds?	1
22. How well could you localize sounds?	1
---------------	Submit